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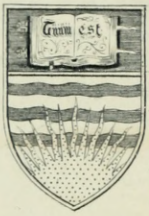

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MINERALS IN PASTURES

Minerals in Pastures

& their Relation to Animal Nutrition

by

J. B. ORR,

D.S.O., M.C., M.A., D.Sc., M.D.

with the assistance of

HELEN SCHERBATOFF

From the

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ROWETT RESEARCH INSTITUTE

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PREFACE

It is well known that, apart from bulk, the feeding value of pasture varies in different areas, and it has been shown in recent investigations that one of the important factors in determining the feeding value is the amount of calcium, phosphorus and other minerals present. Some pastures, indeed, are so poor in one or other of these elements that the deficiency is the cause of disease in grazing animals.

In 1926, the Civil Research Committee of the Cabinet, knowing that these deficiencies occur in several areas in the British Empire, appointed a Sub-Committee of experts, with certain administrative officers, to consider and report on the relationship between the mineral content of pastures and their nutritive value. This Sub-Committee, which is still in being, consists of :

Major Walter Elliot, M.B., D.Sc., M.C., M.P.,
Parliamentary Under-Secretary of State for Scotland.
(*Chairman.*)

Sir Walter Fletcher, K.B.E., F.R.S.,
Secretary, Medical Research Council.

Sir Robert Greig, M.C., LL.D.,
Chairman, Board of Agriculture for Scotland.

Sir Daniel Hall, K.C.B., LL.D., F.R.S.,
Chief Scientific Adviser, Ministry of Agriculture and Fisheries.

A. P. Waterfield, Esq., C.B.,
Assistant Secretary, Treasury.

Sir Thomas Middleton, K.B.E., C.B., LL.D.,
Commissioner, Development Commission.

Professor T. B. Wood, C.B.E., F.R.S.,
Professor of Agriculture, Cambridge University.

Sir L. J. Kershaw, K.C.S.I., C.I.E.,
Assistant Under-Secretary of State, India Office.

C. J. Jeffries, Esq., O.B.E.,
Colonial Office.

Dr. J. B. Orr, D.S.O., M.C., M.A., M.D., D.Sc.,
Director, Rowett Research Institute, Aberdeen.

A. F. Hemming, Esq., C.B.E.,
Assistant Secretary, Committee of Civil Research.
(*Secretary to the Sub-Committee.*)

To ascertain to what extent deficiency of minerals in pastures was the cause of malnutrition in cattle and sheep, there was issued to the various Governments within the Empire, a questionnaire, accompanied by a memorandum giving the gist of what was known on the subject. The replies to this questionnaire showed that malnutrition due to this cause was common in pastoral areas, and was in fact already engaging the attention of a number of Government officers.

The Sub-Committee, having considered the information obtained from the replies to the questionnaire, and from other sources, reported that the subject was one of economic importance, and that a systematic investigation was warranted. They recommended that an important part of the investigation should consist of a search of the literature, to collect and arrange in an easily accessible form all the available information bearing on the subject.

The Civil Research Committee, having considered the report, decided that an investigation should be undertaken accordingly, and recommended to the Empire Marketing Board that a grant might be made to defray the cost of the work. On this recommendation several grants in aid of research work on the subject have been made. Work supported by grants from the Empire Marketing Board is now in progress in Britain, Australia, New Zealand and

East Africa, and schemes of work in other parts of the Empire are under consideration.

The search of the literature was carried out by Miss H. Scherbatoff, working under the supervision of Dr. Orr, in the Reid Library of the Rowett Institute, where a good deal of information bearing on the subject had previously been collected. At the request of the Sub-Committee, the information so far obtained has been brought together by Dr. Orr in the present review, with the object of having it circulated to various officials and research workers throughout the Empire who are interested in the subject.

WALTER E. ELLIOT.

June 1928.

NOTE

In July, 1928, copies of this review were issued to the Officials and Research Workers referred to in the preface, with a request that any further information on the subject which they might have, and which was not included, might be communicated to the writer. Nearly all who received copies have replied. The information obtained in these replies has been incorporated in this issue and has enabled it to be more complete and accurate than would otherwise have been the case.

In addition to the exchange of information and ideas by correspondence, the writer has had, during the last five or six years, opportunities of meeting most of the workers within the Empire who are carrying on research on the Mineral Content of Pastures. In the case of many of the senior workers he has discussed the subject with them both at their own stations and on occasions when they visited the station at Aberdeen. Pleasant memories are retained of discussions at such places as Onderstepoort, Pretoria; the Waite Institute, Adelaide; the University and the Glenfield Research Station, Sydney; the Wallaceville Veterinary Research Station, and the Agricultural Department, Wellington; the Experimental Farm and Veterinary Research Station at Ottawa, and the Agricultural Department and Veterinary Research Station, Nairobi.

While the compiler must accept responsibility for errors and omissions, the credit for this review, if there be any, belongs to these research workers and others who have so freely given constructive criticism and supplied information, some of it not yet published, and in other ways co-operated.

It is impossible to make individual acknowledgment to all those who assisted. Special mention may be made, however, of one of these research workers—Dr. E. Cruickshank, who has herself done a good deal of original research referred to in the text. She has read the proofs, checked the references and in other ways rendered valuable assistance seeing this issue through the press.

While the main work of abstracting the literature was done at the Reid Library, use was also made of certain libraries in or near London, especially the Library at Rothamsted and that of the Ministry of Agriculture, in both of which Miss Scherbatoff and Miss North, a voluntary assistant, worked for several months and received valuable assistance from the Librarians.

Acknowledgment to American workers is made at the end of Chapter VIII.

J. B. O.

December 1928.

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FOREWORD

THE subject of nutrition, always one of great interest, has, especially in the present century, been the subject of intensive scientific study.

Formerly the aspect of the problem to which most attention was devoted was that simply of the balance of intake and output either stated in terms of energy, or in terms of absolute amounts of protein, carbohydrate and fat. The concern was for anabolism and catabolism rather than for metabolism. Such an attitude is perhaps not to be wondered at, for the concept of the body as a form of heat engine is both simple and attractive, so interesting indeed that it has taken about the best part of a century to exhaust its significance.

As our knowledge of the chemical nature of the various substances ingested as foodstuffs increased, particularly so in the case of protein, it soon became apparent that mere measurement of total nitrogen intake and total nitrogen output gave but a feeble view of the complexity of the metabolic processes involved. Thus when it was discovered that the various amino acids, the building stones, of the protein molecule were not all apparently of equal biological value, and further that these essential constituents of a diet could not be synthetised by the living animal body but had to be ingested in a preformed state, the field of work rapidly extended. Then later came the conception of Hopkins, elaborated in great detail by American workers like Mendel and Osborne, that there

must be present in addition, in any diet which claimed to be biologically adequate, substances to which the name of accessory food factors or vitamins was applied. This work in turn led to the appreciation of what are generally known as " deficiency diseases," *i.e.* diseases which are not due to the presence of some adverse factor, but to the absence of a beneficial one.

There is no need here to expatiate on this aspect of the nutritional problem, as we are still in the full tide of the investigation and the work is fully dealt with in many books, journals and reports.

Although much of the earlier work referred to human nutrition, either directly or indirectly, investigation has also been steadily pursued on the nutrition of the larger (farm) animals. Concentrated work on a wide front in animal nutrition has led many investigators, and amongst them Dr. Orr, the author of this monograph, to the conclusion that, in the nutrition of farm animals also substances accessory to the energy-yielding materials of a diet are of prime importance and that their absence leads to deficiency disease.

As regards the nature of these substances consideration showed that, owing to the various differences in the nature of the food and environment which exist between human beings and stock animals, and the greater rate of growth of the latter, with, of necessity, a concomitantly increased demand for building material, the mineral salts were the non-energy yielding components of a diet which were, in the first instance at least, most likely to be lacking or present in ill-balanced proportion in the foodstuffs of stock animals.

Investigation along this line of thought by groups of workers in various parts of the world, notably by Theiler and his colleagues in South Africa, proved that these

deficiencies of essential mineral salts occurred not only amongst stall-fed animals, but also amongst grazing animals ranging freely over wide stretches of country.

In this country, Major Elliot and Dr. Orr came to the conclusion that the whole question of grazing animals and their pasture required reconsideration from the point of view of the possible deficiency of mineral salts. True, at first sight, one would not infer that grazing animals with a large area to feed upon would be liable to such deficiency diseases, since they might be considered to be living on their natural food in their natural environment. But, after all, is it a matter for surprise ? It is, at times, completely forgotten to what an extent the various species of stock animals of the world have been modified, particularly by Western peoples, during the last two hundred years, or how extensive have been the new habitats, of varying geological origin, and growing pastures of varying and often novel flora, peopled by these introduced species.

This process of introduction has been in progress even here in Great Britain. The Highlands of Scotland are at present thickly populated with sheep stocks which, biologically speaking, may be regarded as strange to their environment, particularly so as regards the density of population. It is interesting to note that the Highlands, especially the West Highlands, are precisely the areas where disease amongst sheep is most rife and where there is a notably high death-rate.

It was this aspect of the problem, the Highland sheep areas, which first attracted the attention of Major Elliot and which led subsequently to the detailed examination and investigation of the whole subject by Dr. Orr. In this monograph there is a wealth of illustrative instances and analyses, evidence of concentrated attention and labour. It is a record of patience, thought and skill.

It is not to be inferred that the appreciation of the importance of the various mineral constituents is a new one. It has long been known that various mineral constituents like calcium, phosphorus, iron and iodine, to name only four of them, were as essential for the life of the organism as the energy-giving foodstuffs themselves. But their true significance in the animal organism is not even yet perhaps fully appreciated. The general tendency is to consider a constituent like calcium as a static or inert element whose importance is confined to the bony fabric. But it has been shown that the bony framework is not a mere structural feature, but on the contrary a living storehouse of certain salts which it disburses when required. If our accurate knowledge as regards elements which are present in the organism in relatively large amounts is lamentably deficient, our information regarding and our appreciation of the importance of other elements which are constantly present in traces is negligible. This field of nutritional physiology is practically untilled, and the possibilities both from the strictly scientific aspect as well as the economic are immense. Concerted work on the problem is now in progress in numerous areas both in Britain and overseas.

In the present monograph the whole question of the mineral content of pasture has been reviewed. Dr. Orr felt it necessary to carry out a very full and detailed search of the literature for previous work on the subject. This was all the more difficult as the records of agricultural investigation are especially liable to be lost sight of owing to the scattered nature and often inaccessibility of the publications in which they are printed. It was therefore necessary to go meticulously through all possible journals, since the smaller and more local publications are precisely those in which first-hand " clinical " observations are the

most likely to be found. This thorough search was made possible by a grant from the Empire Marketing Board, which permitted of the employment of two whole time workers. Despite the width of the field covered, even the present review will no doubt be found not to be exhaustive.

Dr. Orr has emphasised the importance of the research work of the earlier investigators of the problem, and repeatedly refers to the fact that there is little or nothing new in most of the work recently carried out in connection with the investigation of pasture. While it is undoubtedly true that records of work have been found covering many of the points which have been dealt with in recent experiments, still Dr. Orr's own work, not merely in making this survey of the literature, but in confirming and adding to the existent data, has been invaluable. Much of the experimental work has, in fact, been repetition, but it was necessary not only because chemical methods and technique have greatly improved, but since without such first-hand knowledge it would not have been possible to grasp the situation as a whole and to evaluate the significance of each individual piece of work in the general scheme.

Both the original data and the survey of work which Dr. Orr puts forward in this monograph renders it a veritable source book to those interested in grassland problems, and it should prove a stimulus to the further development of this field of research, a field rich in both academic and economic problems. The antiquity of the phrase " the salt of the earth " testifies to the esteem in which the mineral constituents of nutrition have always been held.

E. P. CATHCART.

CHAPTER I

INTRODUCTION

PASTURE is the natural food of the species of herbivora which have been domesticated. It is therefore the natural raw material of the most important animal products, viz.: milk, meat, wool and hides. Indeed, the greater part of the world supply of these primary necessities is drawn from animals whose food consists entirely of pasture, either grazed direct or preserved as hay. Even in modern intensive methods of production when other foodstuffs such as cereal grains, oil cakes, residues, roots and silage are used to maintain a high level of productivity, pasture is still the most important foodstuff. According to Wood,[1] in the British Isles the amount of coarse fodder, *i.e.* pasture and hay made from pasture land fed to animals, is weight for weight three times the amount of these concentrated foodstuffs. Further, though these concentrates are valuable foods for maintaining high levels of production, they can only be regarded as supplementary to pasture, which is the natural food of the ruminant, and the only single food on which it can be maintained in health indefinitely.

Economic Importance of Pastures.—The economic importance of the pastures of the British Empire has recently been discussed by McDougall.[2] He estimated that the value of the amounts of grassland products annually consumed in Britain is roughly £426,000,000. Considerably more than half of these is imported, the imports forming nearly a quarter in money value of our total imports.

On the other hand, grassland products form a large proportion of the total exports of the overseas Dominions, *e.g.* in percentage—Irish Free State 55, Australia 60. Canada is an agricultural rather than a pastoral country, and only 17 per cent. of her "primary production" is derived from grasslands. New Zealand, however, is predominantly pastoral and 94 per cent. of the exports from that Dominion consist of pasture products. The annual crop of "grass" is thus one of the main sources of the wealth of the Empire.

In the British Isles there are 34,000,000 acres of grass of one kind or another, and there are enormous tracts of pasture lands in the Dominions and Colonies. As pasture is the raw material of many of the primary necessities of life, for which there is a constant market, the improvement and better exploitation of these pastures is one of the surest methods of securing the stable prosperity of the Empire.

Lines of Research.—In the past, research on grassland problems has been carried out chiefly by botanists and soil chemists. The great improvement in cultivated pasture which has taken place in this country during the past few years is due largely to the efforts of the plant breeders. By selective breeding they have produced plants of higher feeding value, and they have obtained the necessary knowledge to enable mixtures of seeds of different species to be made, so that there will be, throughout the grazing season, a regular succession of plants at the stage of growth at which their feeding value is highest. Equally important has been the work done to determine the effect on pasture of the application of slag and other fertilisers. Investigations along these lines are being continued and are certain to yield further results of practical value.

In the last few years, however, new lines of investigation have been opened up. The scope of the work has been

extended by biochemists and physiologists, who have approached the problems from a new point of view. They are interested not in pasture, as such, but in the effects of different types of pasture on the nutrition of the grazing animal. They are studying the chemical composition of the herbage to determine to what extent this can be correlated with its feeding value. To what extent is the low value of certain types of grazing due to deficiency of one or more of the nutrients now known to be essential constituents of the diet? To what extent is the higher value of better pastures due to the absence of such deficiencies and the better balance of these nutrients? Results of recent research are supplying answers to these questions.

This interest of physiologists and biochemists in pasture problems has arisen from the recent development of the science of nutrition. The caloric or "starch" value and the percentage of protein present, no longer occupy almost the whole attention of those studying the nutritive value of different foodstuffs. It is now recognised that animals are more likely to suffer from a lack of inorganic salts, or of organic substances of unknown composition which are required in comparatively small amounts, than from an insufficiency of the proteins and fat-forming substances which form the main bulk of the food.

Significance of Chemical Composition.—The idea that the nutritive value of pasture is dependent upon its chemical composition is not new. Before the middle of the last century, it was shown that malnutrition in cattle fed on hay grown in certain districts was due to the poverty of the hay in some of the inorganic salts, and as early as 1873, Müller[3] suggested the chemical analysis of German pastures as a means of determining their feeding value, and also of ascertaining what fertilisers should be applied to the land in different districts to obtain hay

sufficiently rich in all the necessary inorganic salts. Much of the modern work is based on similar ideas, which indeed have occurred independently to many different investigators. But whereas individual workers of last century usually confined their attention to a specific " deficiency disease " occurring in definitely localised areas, we now know that kindred nutritional diseases occur in a great many districts throughout the world, and that there may be a deficiency not of one, but of several essential food constituents. Further, we realise that there may be deficiencies which, though not so marked as to cause gross signs of disease, yet limit the rate of growth and the rate of productivity; and further, we now suspect that these deficiencies may adversely affect the " constitution " of the animal, rendering it more susceptible to some diseases of bacterial origin. In short, we have arrived at the conclusion that apart from the question of bulk, the nutritive value of a pasture depends on the extent to which it contains all the essential food constituents in the amounts and proportions required by the animal.

The constituents most likely to be deficient are the inorganic salts. Hydrogen and oxygen are obtained from water, carbon from the atmosphere, and nitrogen from the atmosphere and the soil. These four elements are the basis of the great " organic compounds " which constitute by far the greater part of the food substance. But the mineral elements, phosphorus, calcium, sodium, chlorine, iodine, etc., if not present in the soil in sufficient amounts and in a form available to the plant, cannot be obtained in appreciable amounts from the rain or atmosphere. There is evidence to show that such deficiencies do occur in wide areas, and that these deficiencies limit the rate of growth and production, and also affect the health of cattle and sheep.

A good deal of work is now being done on the nature and occurrence of these deficiencies, both by veterinarians whose interest is the effect of the deficiencies on the grazing animal, and also by agronomists who are interested in the wider general problems of pasture husbandry. Some of the results being obtained appear to be of considerable economic importance, and it is likely that in the next two or three years there will be a good deal of work done along practical lines to apply the information which is now being obtained. In the following chapters an attempt is made to bring together the available information likely to be of use to those engaged in this work.

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3. Müller, H.: *Landw. Jahrb.*, 1873, ii. 1-107.

CHAPTER II

THE MINERAL CONTENT OF PASTURES

Historical.—The earliest work bearing on this subject which we have been able to trace is that of de Saussure (1804).[1] He investigated the ash constituents of plants and came to the conclusion that the ash varied with the nature of the soil and with the stage of growth of the plants. Later Sprengel (1832),[2] who also studied the nature of the ash of plants, suggested that the ingredients of the ash were of importance in the nutrition of animals. It is remarkable that these pioneer investigators of plant physiology should have, thus early, reached these conclusions which modern work is showing to be of fundamental importance in connection with the nutritive value of pasture.

In the latter half of the nineteenth century, the ash of hay grown in certain districts where endemic diseases occurred in herbivora, was investigated by several European workers, with the object of determining whether these diseases could be correlated with the chemical composition of the herbage, and during the last twenty years work of a similar nature has been carried out in South Africa, Australia and New Zealand. In the course of these investigations, carried out from the point of view of the etiology of disease, it was found that there were marked differences in the percentages of calcium and phosphorus in pastures grown in different areas, those from the districts in which the diseases occurred being usually abnormally poor in one or both of these elements.

The first systematic work on the chemical composition of the herbage was done by Lawes and Gilbert (1856-1900).[3] In the course of an extensive investigation of factors affecting the botanical and chemical composition of the herbage of permanent grassland, detailed analyses of the ash were done. The results showed that the chemical composition of the mixed herbage was closely dependent on the botanical composition and the stage of development of the plant. They also showed that " the mineral composition of the mixed herbage is very directly dependent on the supplies available within the soil. Indeed the composition of the mixed produce was found to be a somewhat close reflection of the supply available within the range of the roots." This classical research thus supplied a solid basis of experimental evidence for the suggestion put forward by de Saussure.[1] It is interesting to note that work on these grass plots laid out at Rothamsted in 1856 is still being continued. An account of the recent work is given in a monograph by Brenchley.[4]

During the last few years a mass of analytical data on the mineral content of pastures has been accumulated in the course of an investigation carried out at the Nutrition Institute at Cambridge University and the Rowett Institute, Aberdeen (Elliot, Orr and Wood).[5-10] As the following discussion is largely based on this data, reference may be made to the origin and nature of this work. The researches at the latter Institute had emphasised the importance of minerals in the nutrition of farm animals, and it was suggested that the known differences in the feeding value of pastures in different localities might be associated with differences in the amounts and proportions of the various " inorganic " constituents of the herbage. Preliminary work in Aberdeen in 1921-22 yielded results supporting this hypothesis, and in 1923 at the suggestion of Major Elliot,

there was begun a systematic investigation of the chemical composition of pastures, from the point of view, not of the crop, but of the grazing animal. Samples of pasture were collected from many different grazing areas in Britain and from some overseas parts of the Empire. The samples were collected in the summer months during the period of plant growth. The areas sampled included cultivated pastures and natural hill pastures. In all, over 400 samples of pasture were analysed. At the time of collection of the samples, information with regard to the feeding value of the grazing was obtained from the shepherds and herdsmen, special note being taken of the number of animals grazed per acre, the rate of growth of young animals and the incidence of disease. In addition to protein, fat, nitrogen-free extractives and fibre, the "total ash," "silica-free ash," calcium, phosphorus, sodium, potassium and chlorine, and in some cases iodine, iron, manganese and magnesium were estimated.

As this joint investigation has proceeded, the attention of workers at Cambridge has tended to be directed to the chemical composition and nutritive properties of good cultivated pastures, and that of the workers at Aberdeen to the problems connected with natural pastures whose mineral content is known to be below the requirements of the grazing animal.

Some work on the mineral content of pastures has also been done recently at the Welsh Plant Breeding Station, from which several papers have been published showing the amounts of some of the ash ingredients in different parts of the plant and at different stages of growth.

The foregoing account shows the nature of the investigations in the course of which information on the mineral content of pastures has been obtained. It will be noted that in this work there have been two rather different objectives.

On the one hand, the centre of interest has been the nutrition of the plant, the work being done, as Lawes and Gilbert put it, "from the agricultural point of view." On the other hand the chief interest has been the influence of the composition of the herbage on the nutrition of the grazing animal, the work being done from the veterinarian point of view. The latter work has necessitated a more detailed analysis of the ash constituents, which makes it more interesting in the present connection. It is, therefore, referred to here more fully than the former.

THE PERCENTAGE OF MINERALS IN DIFFERENT KINDS OF PASTURES

A. CALCIUM, PHOSPHORUS, SODIUM, POTASSIUM AND CHLORINE

The above elements can be conveniently treated together. They are the ones required in largest amounts, and in investigations on deficiency diseases in grazing animals attention has been directed chiefly to these five. There are, therefore, more analytical data on these than on the other mineral elements.

Good Pastures.

Composition.—In Table I Godden [8] gives the average composition of the dry matter of cultivated pastures collected from different areas in Scotland and England. The figures are the means of the individual analysis of 24 samples, and the probable error for the percentage of each constituent is given. The calculated caloric value is also shown. In making this calculation, it was assumed that 40 per cent. of the ether extract is digestible fat, and that the total nitrogen-free extractives are equal to the sum of the digestible nitrogen-free extractives and the digestible fibre.

TABLE I

AVERAGE COMPOSITION OF 24 SAMPLES OF CULTIVATED PASTURES. RESULTS EXPRESSED IN PERCENTAGES OF DRY MATTER.

	%	Probable Error.
CaO	1·004	±·039
P_2O_5	0·735	±·032
Na_2O	0·246	±·023
K_2O	3·177	±·137
Cl	0·950	±·036
N	2·825	±·123
Total Ash	9·787	±·282
Silica-free Ash	6·637	±·206
Fibre	23·0	±·64
Calories per 100 gms.	268·9	±1·8

Since the above figures were published a statistical analysis of 48 samples of cultivated pastures, including the above 24 and other samples collected at different periods of the grazing season, has been made by Thomson.[11]

TABLE II

AVERAGE COMPOSITION OF 48 SAMPLES OF CULTIVATED PASTURES. RESULTS EXPRESSED IN PERCENTAGES OF DRY MATTER.

CaO	1·104
P_2O_5	·765
*Na_2O	—
K_2O	2·969
Cl	·903
N	2·932
Total Ash	9·725
Silica-free Ash	6·971
Fibre	23·2
Calories per 100 gms.	268·9

It is seen that these more recent figures correspond closely with those quoted in Table I. They may be taken, therefore, as an approximation of the composition of good cultivated pasture in Great Britain.

* The figure for Na_2O is omitted since some of the data for this constituent in the later set were not available.

Nutritive Value.—In considering the mineral content of a pasture in relation to its nutritive value, it is necessary to have some standard of the requirements of animals for the different minerals. Milk is the food specially prepared by nature to supply all the essential constructive materials required for growth. It can be assumed, therefore, that the mineral content of milk corresponds closely with the mineral requirements of the young animal. It is obvious also that it will bear a close relationship to the requirements of the lactating animal. In the present state of our knowledge the amount of minerals found in milk affords the best available standard for growing and lactating farm animals.

As the amount of food needed by an animal is determined by its energy requirements, the truest basis of comparison is the energy unit. Table III compares the amounts of the chief essential minerals found in the quantities which yield 1000 calories of (*a*) cow's milk ; (*b*) good pasture ; and (*c*) representatives of some common feeding-stuffs.

TABLE III

COMPARISON OF MINERAL CONTENT OF GOOD PASTURE WITH THAT OF SOME OTHER FOODSTUFFS, WITH MILK AS THE STANDARD.

1000 CALORIES CONTAIN THE FOLLOWING AMOUNTS IN GRAMS :

	CaO	P_2O_5	Na_2O	K_2O	Cl	Nitrogen.
Cow's Milk - -	2·38	3·43	0·81	3·21	1·4	8·32
Good Pasture - -	3·64	2·75	0·94	11·54	3·5	10·40
Maize - - -	0·03	1·83	0·13	1·36	0·001	4·64
Wheat - - -	0·14	2·75	0·13	1·59	0·2	5·60
Potatoes - - -	0·28	1·60	0·49	5·56	0·3	3·36
Turnips - - -	1·18	1·96	0·33	5·40	0·42	3·87
Decorticated Cotton Cake - - -	1·22	11·26	0·24	8·05	0·11	26·32
Molasses - - -	5·35	0·56	1·02	10·26	3·56	4·23

It will be seen that there is a fairly close resemblance between the mineral content of good pasture and that of cow's milk. There is no natural foodstuff so well balanced

in this respect as good pasture. Compared with milk each of the other representative foodstuffs quoted in the above table is deficient in one or more minerals. The close correspondence of the mineral content of a good pasture to the mineral requirements of the animals is doubtless one of the most important factors in the well known high nutritive value of pasture for promoting growth and maintaining health in herbivora. Indeed, the well known value of "green food" for the health of any species is to a large extent due to its mineral content, which has a general resemblance to that of pasture.

In cases where the pastures have been manured intensively the percentages may be considerably higher than the average figures quoted above. Thus, the analysis of a sample of pasture from Lord Astor's paddock in Buckinghamshire, where racehorses are grazed, yielded the following result (Godden): [8]

PERCENTAGES ON THE DRY MATTER.

CaO %	P_2O_5 %	Na_2O %	K_2O %	Cl %	N %	Total ash.	Silica free ash.	Fibre.	Calories per 100 gm.
2·473	0·997	0·698	2·398	0·498	3·562	11·97	8·68	20·25	271

MINERAL CONTENT COMPARED WITH THAT OF MILK.

1000 calories contain the following amounts in gms.

	Cow's Milk.	Highly Manured Pasture.
CaO - -	2·38	9·13
P_2O_5 - -	3·43	3·68
Na_2O - -	0·81	2·58
K_2O - -	3·21	8·85
Cl - -	1·4	1·84
N - -	8·32	13·14

It will be seen that the amount of constructive material (*i.e.* protein and minerals) per 1000 calories is higher than in the case of cow's milk. It is therefore possible to produce a

type of pasture which for the average class of herbivora is actually too rich in minerals. In recent Cambridge work (Woodman) [12] it has been shown that good pasture at the stage of growth when it has the highest concentration of constructive material, *i.e.* protein and minerals, while well balanced for growing or lactating animals, is too rich in these nutrients for fattening animals, which require a high proportion of carbohydrates. The interesting problem of the correlation of the composition of pastures to the requirements of different types of animals is discussed in Chapter IV.

Poor Pastures.

Composition.—The foregoing observations refer to cultivated pastures where the natural herbage has been altered by the treatment of the soil, including the application of mineral fertilisers, and the sowing of grass mixtures consisting of seeds of plants of known high nutritive value. In Table IV the composition of cultivated pastures is compared with that of natural pastures which are usually of lower nutritive value. The groups of samples are arranged in descending order of feeding value.

TABLE IV

AVERAGE MINERAL CONTENT OF DIFFERENT TYPES OF PASTURE.

	No. of samples.	Silica free ash.	CaO %	P_2O_5 %	Na_2O %	K_2O %	Cl %	N %	Fibre %	Calorie 100 gm.
Cultivated pasture	24	6·64	1·00	0·74	0·25	3·18	0·95	2·83	23·0	269
Natural pasture "all grazed"	22	5·85	0·65	0·67	0·37	2·66	0·64	2·50	24·5	275
Poor hill pasture "partly grazed"	35	5·49	0·56	0·60	0·41	2·60	0·60	2·54	25·2	271
Island of Lewis	1	—	0·29	0·24	0·38	0·68	0·12	1·34	25·7	230
Falkland Islands	55	4·56	0·29	0·54	0·31	2·20	0·70	1·95	29·3	248

Nutritive Value.—The information recorded at the time of the collection of the samples shows that the feeding value of the pastures as determined by the number of animals grazing per unit area, the rate of growth of the young, the percentage fertility and the health, are roughly parallel with the percentage " silica-free ash " which represents the total metabolisable minerals. Thus the samples of the poor natural pasture " partly grazed " were obtained chiefly from Argyllshire and neighbouring counties in the West of Scotland. The sheep there are small, the fertility is comparatively low, and the average mortality is over 10 per cent. (Reid).[13] In the Falkland Islands, from which the worst samples were obtained, the fertility and mortality figures as given by Munro [14] were: Lambs born, 90%; surviving at dipping, 52%.

Although there are a good deal of analytical data, referred to later, showing a low percentage of some individual mineral in pasture or hay, which produces diseases of malnutrition, there are no other data showing the general relationship of mineral content and feeding value with which the above can be compared. The idea that the nutritive value of pasture is related to its mineral content is, however, not new. As far back as 1860 Konig [15] records the results of analyses of some samples of good and bad hay, showing that in the two samples of bad hay the percentage of minerals was respectively 4·37 and 4·95 whereas, in three samples of good hay the percentage varied from 5·15 to 6·0.

Selection by the Grazing Animal.—It is known that on natural uncultivated pastures certain parts are grazed in preference to others. In the survey of hill pastures, samples were taken both of the herbage actually " eaten " and of the herbage in the same area which was " not eaten." The following table (Godden) [8] shows the average difference in composition in 35 pairs of corresponding samples.

TABLE V

AVERAGE COMPOSITION OF SAMPLES OF SCOTCH HILL PASTURES. RESULTS EXPRESSED AS PERCENTAGES OF DRY MATTER.

	Grass Eaten.	Grass Not Eaten.
CaO	0·56	0·30
P_2O_5	0·60	0·37
Na_2O	0·41	0·17
K_2O	2·60	1·61
Cl	0·60	0·33
N	2·54	1·82
Silica-free Ash	5·49	3·13
Fibre	25·2	29·3

The "eaten" samples were taken from plants whose leaves and stems had been cut across in grazing. They are therefore not strictly comparable with the "not eaten" samples which contained the full leaf and stem. Further, in many cases on account of the fact that they had not been cropped, the "not eaten" samples were more mature. The cause of the difference, however, need not be discussed. The point of interest is that on poor pastures with a low mineral content the herbage selected by animals with a free choice is richer in minerals than that left uneaten. Recently Fagan and Evans [16] have shown that the part of the plant selected by the sheep in grazing, *i.e.* the leaf, is richer in calcium and silica-free ash than the remainder. It is well known that when a patch of poor pasture is slagged the grazing animals prefer that part to the untreated area. It will be shown later (Chap. III) that the application of slag increases the percentage of minerals in the herbage. Animals grazing on poor pasture have thus a natural instinct which leads them to select the foodstuff most suitable to their needs. An exaggeration of this instinct, leading to the eating of abnormal substances such as earth or bones, appears in cattle and sheep grazing on pastures which are markedly deficient in some mineral element (Chap. IV).

Correlation of Minerals, Protein and Energy Value.

Reference to Table IV, p. 13, shows that there is a definite correlation between protein and minerals. Pastures which are low in minerals tend to be low also in protein.

There is no evidence of any correlation between the mineral content of pasture and its caloric value. Indeed, there is comparatively little difference between the caloric value of good cultivated pasture and the poorest type of natural pasture. The calculation of the caloric value in these tables is done by the conventional method, and is based on the assumption that 40 per cent. of the ether extract is digestible fat, and the total nitrogen-free extractives are equal to the sum of the digestible nitrogen-free extractives and the digestible fibre. It is probable that this conventional method of calculating the caloric value is not strictly applicable to poor pastures. The fibre may be more indigestible or the digestibility may be affected by lack of mineral salts. This interesting question of the digestibility of low grade pasture is now being investigated at Cambridge.

Thomson [11] worked out the coefficients between the different minerals in samples of both cultivated and natural types. His figures are given in Table VI, p. 17.

It will be seen that the correlation between the minerals tends to grow closer as we pass from left to right of the table, *i.e.* the correlation between the minerals is higher in the case of the poor pastures than in the richer cultivated areas. The application of manures has had the effect of increasing a limited number of elements, or of facilitating the absorption of some more than others, and so upsetting the close correlation found in the unfertilised herbage.

It is apparent that samples with low percentages of one

constituent tend to have low percentages of the others, owing to the fact that the available amount of one element becomes a limiting factor for the utilisation of the others, either by limiting the absorption of the others, or by limiting the growth and spread of the plants naturally rich in minerals. This is brought out more fully in Chapter III, where the factors affecting the mineral content of pastures are discussed.

TABLE VI

PASTURES—CORRELATIONS.

No. of Samples	48	37	41	40
		Hill Pasture.		
	Cultivated.	"Eaten."	"Not Eaten."	Falkland Islands.
K_2O and Cl	·79 ±·054	·76 ±·069	·92 ±·023	·93 ±·021
P_2O_5 and Cl	·45 ±·115	·41 ±·137	·73 ±·074	·78 ±·062
CaO and Cl	−·17 ±·140	·52 ±·120	·39 ±·133	·51 ±·118
K_2O and P_2O_5	·63 ±·087	·07 ±·164	·68 ±·085	·81 ±·054
CaO and K_2O	−·13 ±·142	·62 ±·101	·43 ±·127	·53 ±·114
CaO and P_2O_5	·29 ±·132	·19 ±·159	·48 ±·121	·45 ±·126
CaO and N	·29 ±·132	·33 ±·146	·50 ±·117	·58 ±·105
P_2O_5 and N	·85 ±·041	·51 ±·121	·51 ±·114	·87 ±·040
K_2O and N	·74 ±·066	·47 ±·128	·85 ±·044	·91 ±·027
Cl and N	·55 ±·101	·51 ±·121	·69 ±·082	·87 ±·040

Though as a general rule the percentages of the various minerals in poor pastures tend to run more or less parallel, pastures which are markedly deficient in one mineral may be much more deficient than the others. This is shown by the following table, which gives the amount present in three different grades of pasture, expressed as percentages of the amount in cultivated pasture. In all these grades calcium is believed to be the limiting factor.

TABLE VII

	CaO	P_2O_5	K_2O	Cl
Cultivated	100	100	100	100
Good Natural	65	90	84	67
Poor Natural	56	81	82	63
Falkland Islands	29	73	69	74

It will be seen from the above table that while phosphorus, potassium and chlorine fall with calcium, the fall in the case of calcium, the element which was most deficient in the soil, is more marked than in the case of the others.

The same relationship is found in pastures grown on soils when phosphorus is the limiting factor, as for example in South African soils. In these pastures the percentages of all the minerals tend to be low, but the poverty in phosphorus is out of all proportion to that of the others (p. 19).

It is on these pastures in which there is an extreme deficiency of one element that deficiency diseases are most liable to occur. In the following section illustrations of these abnormal types of pasture are given.

Pastures Markedly Deficient in Individual Minerals.

There are a number of recorded analyses showing specially low percentages of individual minerals. In these cases the ratios of the amounts of the minerals to each other differ widely from those found in normal pastures. One of the first workers to make observations on this subject was Germain (1881),[17] who noted that the relationship of calcium to phosphorus in the ash of Cochin China hay, which was deficient in calcium, was very different from that shown by the analyses by Boussingault of hay which was specially rich in calcium.

	Percentages on the Ash.	
	CaO	P_2O_5
Ash of Cochin China Hay -	2·97	5·3
Ash of Hay—Boussingault -	20·58	7·8

Ingle,[18,19] who lays special stress on the ratio of calcium to phosphorus as an important factor in the nutritive value of the pasture, showed that certain South African pastures were very poor in both calcium and phosphorus, the average

percentages of six samples of hay being ·135 CaO and ·278 P_2O_5. Low percentages were also found in green fodder, *e.g.* :

PERCENTAGES ON DRY MATTER.

	CaO	P_2O_5
Tall Fescue - - - -	·31	·12
Sheep's Parsley - - -	·50	·16

Even lower percentages of phosphorus in South African pastures have been recorded by later workers. Theiler *et al.* [20] found percentages as low as ·04 in certain samples. In these samples, abnormally poor in phosphorus, there is no correlation between phosphorus and calcium. This may be seen from the following table showing seasonal variations :

TABLE VIII

ANALYSES OF DRY MATTER OF HERBAGE AT ARMOEDSVLAKTE.

Date.	P_2O_5	CaO	P_2O_5 : CaO
8th Dec., 1919 -	·32	·59	1 : 1·84
15th Jan., 1920 -	·22	·50	1 : 2·27
4th March, 1920 -	·24	·43	1 : 1·78
19th April, 1920	·11	·46	1 : 4·18
11th May, 1920 -	·07	·50	1 : 7·14
8th June, 1920 -	·09	·59	1 : 6·55

Some samples from Kenya Colony analysed at the Rowett Institute, 1926-27, showed great poverty in phosphorus, without a corresponding extreme poverty in calcium, *e.g.* :

	P_2O_5	CaO
Nakuru District - - -	·32	·40
Molo District - - - -	·19	·49

Very low percentages of phosphorus have been noted by Australian workers. In twelve samples of native grasses, Kincaid [21] found percentages ranging from ·099 to ·299. These correspond with results of analyses by Cherry,[22] who found ·129% in southern tree grass, ·122% in kangaroo grass and ·170% in tussock. Unfortunately, the amounts

of the other mineral constituents were not determined. These figures illustrate the well known general shortage of phosphorus in the pastures of wide areas in both Africa and Australia.

Abnormal ratios of sodium and potassium have been recorded by various workers on the continent of Europe. Zuntz [23] analysed the ash of a number of different kinds of hay, some of which were of very low nutritive value, and found a marked difference in the relative proportions of these minerals present, *e.g.*:

PERCENTAGE PRESENT IN ASH.

	Na_2O	K_2O
Normal Brandenburg Hay -	5·43	20·00
Black Forest Hay - - -	0·21	37·40

He attributes malnutrition in the cattle fed on the Black Forest hay to the high ratio of potassium to sodium.

Later Popp,[24] investigating the cause of malnutrition in cattle fed on certain hays, also found marked differences in the ratios both of sodium, potassium and other constituents. The following table shows the amounts of the various constituents present for every 100 parts of CaO in four samples analysed by him.

TABLE IX

	1	2	3	4
CaO - - -	100	100	100	100
K_2O - - -	815	84	950	452
Na_2O - - -	141	66	206	69
MgO - - -	51	36	52	55
Fe - - -	10	3	5	—
P_2O_5 - - -	295	51	339	118
SiO_2 - - -	397	112	235	111
Cl_2 - - -	316	68	471	203
SO_3 - - -	207	64	262	63

In samples analysed at the Rowett Institute, greater differences were found in ratios of potassium and sodium

than in the case of the other mineral constituents. These differences were especially marked in the samples from the Romney Marshes. The two following examples, from different fields, show how widely the sodium : potassium ratio may vary :

	Na_2O %	K_2O %
Field A - - - -	0·005	4·745
Field B - - - -	0·440	1·728

In the first case there is about one part of Na_2O to 950 of K_2O, and in the second case the ratio is about 1 : 4.

Wide variations have been found in the chlorine content of pastures in over 200 samples analysed at the Rowett Institute. The lowest—·015%—was found in a sample from Kintyre, Scotland, and the highest—1·71%—in a sample from Montgomeryshire. Nessler [25] in seven samples found the highest to be ·39% and the lowest ·10%. The extremes, found in Wolff's *Aschen-Analysen*,[26] are ·04 for the lowest and ·83 for the highest figure of twenty samples of grasses.

In the above review we have dealt with the effect of deficiency of one element limiting the assimilation of the others. Excess of an element, however, may also have the same result. Thus, Gile and Ageton [27] found that, with heavy dressings of limestone, while the calcium content in certain plants was markedly increased, there was a diminution in the iron content.

Johnson [28] gives data indicating that if manganese is present in the soil in considerable amounts it tends to retard the assimilation of iron by the plant.

Reed and Haas,[29] working with young orange trees in sand cultures in California, found that the percentage of calcium in the plant bore an inverse ratio to that of potassium. Leaves of trees to which no calcium salts were

applied were very rich in potassium, and, conversely, those receiving no potassium were very rich in calcium.

Godden [10] has shown that this inverse relationship between calcium and potassium occurs also in clover plants. He found that plants grown with a fertiliser containing no potassium had a higher calcium content than those grown with the fertiliser containing potassium. In the same way the potash content was higher in the plants where calcium was omitted from the fertiliser than in those where calcium was included.

B. IODINE, IRON, MANGANESE, MAGNESIUM, SULPHUR, SILICON, FLUORINE, BORON, AND COPPER.

The foregoing discussion has been limited to calcium, phosphorus, sodium, potassium, and chlorine, elements which have been considered of greatest importance in nutrition. Recent work, however, has emphasised the importance of other constituents of the ash.

Iodine.

Since the middle of last century, when Chatin [30] demonstrated the presence of iodine in each of a large number of plants examined, it has been assumed that iodine occurs in pastures. It is only within the last few years, however, that the amounts of iodine in pasture have been estimated. Forbes and Beegle [31] found traces of iodine in hays, silage, and fodder crops, but they considered its presence accidental. Neither Bohn [32] nor Winterstein [33] found iodine in pasture plants which they examined. Following the improvement of the technique of iodine estimations, it has been shown that these negative results were due to the use of methods which were not sufficiently delicate to estimate the small amounts of iodine which occur in average pastures. The

normal occurrence of iodine in pastures is now beyond dispute. The amounts in which it occurs, however, are so small that the mode of expression is in "γ" per 100 gms. ($1\gamma = 0{\cdot}000001$ g.).

v. Fellenberg [34] gives figures for four samples of pastures in Switzerland, and Bleyer [35] for two samples from the neighbourhood of Munich. The amounts found by them vary from about 20 to 40 γ per 100 gms. dry matter. At the Rowett Institute 30 different samples from various parts of the British Isles have been analysed. The amounts found range from 21 γ per 100 gms. dry matter in a Derbyshire sample, to 500 γ in a sample from Romney Marsh in Kent. Most of the samples fell within the range 30 γ to 100 γ. Samples of pasture from East Africa show somewhat similar values, with the exception of one sample gathered in the vicinity of a salt lick which showed the high iodine content of 4850 γ per 100 gms. dry matter. It is evident that iodine is present in all pastures, but that the amount present varies widely, dependent evidently upon the amount of available iodine in the soil (Orr, Stuart and Kelly).[36]

Iron.

Norton, [37] in his analysis of the ash of the stalk and leaf of the unripe oat plant, found percentages as Fe_2O_3 varying from 0·30—0·99. These figures are very similar to those obtained later by Lawes and Gilbert [3] for the ash of mixed herbage of grassland, viz.: 0·35—0·83. Wolff,[26] in his collection of data in *Aschen-Analysen*, quotes figures for grasses and legumes. The highest in a series of analyses by Way and Ogston [38] is 0·23 for grasses and 3·3 for legumes, the lowest being 0·19 for grasses and 0·33 for legumes, the figures being percentages of Fe_2O_3 on the ash. Warrington,[39] in Watt's *Chemical Dictionary*, gives figures on the same basis of calculation varying from 0·58 — 1·73.

The most interesting recent work on the iron content of pastures is that of Aston,[40] who has found that in an area in the North Island of New Zealand the pastures are so poor in iron that grazing animals suffer from deficiency of this element. In samples of clover from the affected area the percentage of Fe in the ash varied between 0·07 and 0·22 compared with figures varying from 0·23 to 1·9 in healthy areas. In thirty samples from hill areas in Scotland, without any reference to disease, the average percentage was 0·328 Fe in the ash (Rowett Institute, unpublished data).

Recently Fagan and Evans[16] have studied the iron content of different parts of plants. Their figures show that on the average the iron (Fe) content of the ash of the stem is slightly higher than that of the leaf, viz.: In the stem the percentage ranged from ·299 to ·342 compared with ·255 to ·266 in the leaf.

Similar results were obtained by Krevs[41] and Norton,[37] the former working on the tobacco plant and the latter on the oat. Latshaw,[42] on the other hand, found the leaf to be rather richer than the stem.

Petit[43] and Czadek[44] have shown that the soil and manuring have an influence on the iron content of the plant which can be increased by the application of soluble iron salts to the soil. Thus, in spinach the percentage of iron in dry matter was raised from 0·03% to 0·23% by the addition of soluble iron salts. The assimilation of iron by plants is affected by the presence of other elements in the soil. Calcium and manganese both appear to retard it (Gile[45]; Johnson[28]).

There are only a few limited areas in the world where the pastures are believed to be deficient in iron, viz.: New Zealand (Aston[46]); Kenya, and South of Scotland (Orr[47]); King Island, Tasmania (Dickinson[48]). The effects of the deficiency are discussed later (Chap. VI and VII).

It should be noted that the figures in this section, with the exception of Czadek's, refer to the percentage of iron in the ash and are, therefore, not comparable with the figures stated in the preceding part of this chapter which refer to percentages of dry matter.

Manganese.

Manganese used to be considered one of those elements which have no particular function in plant or animal nutrition. Its presence in the tissues was regarded as accidental. It is now known, however, that it performs important functions in both animal and plant metabolism.

In animal nutrition it probably plays a rôle in the process of oxidation and in enzyme action. The nature of its functions. however, has not yet been fully elucidated (McCarrison [49] ; Levine and Sohm [50] ; MacHargue [51, 52]).

Manganese occurs in every part of the plant. It is concentrated specially in the seeds, in the green leaves and shoots, and it is believed to have functions in connection with the germination and early development of the plant, and with the photosynthetic process and chlorophyll formation (Bertrand [53] ; Pichard [54] ; Jadin and Astruc [55] ; MacHargue [51, 52]). A disease called "grey speck," which occurs in oats in certain parts of Europe and Australia, is due to deficiency of available manganese in the soil (Samuel and Piper [56]).

With regard to the amount of manganese in pastures, which is the point with which we are chiefly concerned here, Nessler,[25] working with hay, found the percentages as Mn_3O_4 on dry matter (the basis of calculation for all the percentages in this paragraph) to vary from ·035 to ·05, and Neumann and Rheinhardt [57] found ·03. In both of these cases the hay analysed caused "licking disease." Lawes and Gilbert [3] found percentages varying from 0·0155 to 0·0854 and Hall

and Russell [58] from 0·002 to 0·018 for the herbage of Romney Marsh, the high figures being from the poorer quality of pasture. Jadin and Astruc [55] found percentages for different species of plants as follows: Lucerne, ·005; sainfoin, ·0043; vetch, ·0037; trifolium, ·0054; meadow grass, ·017; and Jones and Bullis [59] record the following percentages: vetch, ·0042; red clover, ·0033; alsike clover, ·0068; alfalfa, ·0023; field peas, ·0033; sweet clover, ·0027; white clover ·0034; MacHargue, [51, 52] found ·003 in blue grass, ·0085 in Kentucky blue grass, and ·0176 in orchard grass. Working on the oat, Samuel and Piper [56] found ·014 in healthy plants, while Grimmett [60] records ·013.

There is not sufficient information on the requirements of animals for manganese and on the effect of excess or deficiency in the food to enable us to determine to what extent the feeding value of the pasture is affected by its manganese content.

Magnesium.

The percentages of magnesium have been determined by a number of different workers. Klimmer and Schmidt [61] found amounts varying from ·24% to ·51% of dry matter. More recently, Eckles, Becker, and Palmer [62] found percentages ranging from ·590 to ·709 in alfalfa hay, and from ·322 to ·350 in timothy hay. The amount of magnesium present in pastures is probably in all cases more than sufficient for the requirements of the animals grazing.

Sulphur.

Sulphur is an element of great importance in animal nutrition. As wool is relatively rich in sulphur, it might be expected that in sheep grazings the sulphur content of the pasture would be of importance in determining its feeding value. As a matter of fact, however, we have very little

information on this point. Indeed, we do not know what the requirements of the animals are for sulphur.

Godden [63] determined the sulphur in 31 samples of cultivated pasture in the neighbourhood of Aberdeen, and in 19 samples of uncultivated pasture in various parts of Scotland. The average for the former was 1·071 per cent. as SO_3 on the dry matter, the highest figure being 1·378, and the lowest ·654. On the hill pastures the average was 1·048, the extremes being 1·719 and ·499. There is thus comparatively little difference between good and bad pasture, and there is obviously no correlation between the concentration of sulphur and the other mineral elements. Lawes and Gilbert[3] found a higher percentage of sulphur in leguminous plants than in grasses. They also found that the amount of sulphur increased throughout the season. Their figures, which were obtained by analysis of the ash are, however, probably much too low owing to loss of sulphur in the process of ashing. Godden's figures were obtained by a method adapted to avoid such loss.

Silicon.

Silicon is found in the animal body, and is probably an essential constituent of some of the tissues, but the amounts in animal tissues are so small compared with the amounts in plants, that there is no likelihood of any deficiency of silica, *i.e.* silicon dioxide, in pastures. In the analyses of pastures it is common to determine the total ash and then the silica-free ash. There are, therefore, in the literature many figures in tables of analytical data from which the amount of silica in pasture can be collected, but few writers have considered the subject of sufficient interest to warrant particular mention.

The percentage of silica appears to increase with the growth of the plant. The following figures are taken from

analyses of pastures cut at different times throughout the summer :

	June.	September.	October.
Silica-free ash % - -	5·75	6·12	7·66
Silica - - - -	1·80	3·46	12·72

The same increase throughout the season is shown by the more recent work of Fagan and Jones.[64]

	3rd June.	2nd September.	29th October.
Silica-free ash % - -	5·75	6·12	7·61
Silica - - - -	1·80	3·46	12·72

A series of analyses of stem and leaf of cocksfoot by these workers showed a greater amount of silica in leaf than in stem throughout the season from April to September. The following figures show the percentages :

April.		September.	
Stem.	Leaf.	Stem.	Leaf.
1·45	2·16	3·59	6·90

Fagan and Jones determined silica in a number of different species of pasture, but there seems to be no definite correlation between the species. In pastures the amounts present probably depend upon soil conditions, which need not be considered here.

There is no evidence to show that the percentage of silica is a factor in its nutritive value. In Table II it will be seen that there is no correlation between the percentages of silica and the percentages of the other minerals which determine its nutritive value. Aston,[65] however, has suggested that high silica content of pastures is a factor in preventing tuberculosis.

Fluorine.

Fluorine is an essential constituent of the enamel of the teeth ; little is known, however, with certainty about other functions which it may perform in the body. It is known,

however, that excess of fluorine in the diet interferes with the metabolism of phosphorus and calcium (Schwyzer [66]).

The presence of fluorine in plants has been investigated by Gautier [67] and Gautier and Clausmann.[68] They found in milligrams per 100 gms. of fresh material: 1·30 in lucerne, 2·72 in sainfoin, 0·40 in hay. These figures are not markedly different from those obtained for other plants. In growth experiments they found that in most cases fluorine increased the rate of growth of the plant, though in a few cases it appeared to have an inhibiting effect. There is no information to show whether the amount of fluorine in pastures is a factor affecting its feeding value.

Boron.

Boron occurs normally in small amounts in many, if not all, plants and animals, being more common in animals of marine origin. Bertrand [69] suggests that, like iron, it may play an indispensable part, possibly catalytic, in the cell. For the growth of certain plants, legumes in particular, a trace of this element seems to be essential. Brenchley [70] found that boron increased the growth of peas, but not of barley, in water cultures, at a concentration of 1 in 100,000. Above this concentration harmful effects were produced.

Copper.

Copper is a normal constituent of both plant and animal tissue, but very little is known with regard to its functions, if any, in the body. The recent work of Hart and Steenbock [71] indicates that it is a factor in haemoglobin synthesis, and in some of the lower forms of animal life, copper, instead of iron, is part of the pigment molecule of the blood. It is very possible that minute traces of copper are essential. Analysis by McDougall [72] show that on ordinary soils

plants may contain about thirty milligrams of copper per kilogram of dry matter. We have, however, no data to show the extent to which the concentration of copper in pasture varies, and no information as to whether or not some pastures contain too little copper.

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CHAPTER III

FACTORS AFFECTING THE MINERAL CONTENT OF PASTURES

It has been seen in Chapter II that there are wide differences in the amounts of minerals found in different types of pastures. In the present chapter the factors upon which these differences depend are discussed. They can be conveniently considered under the following heads :

(1) Species of Plants.
(2) Stage of Growth of Plants.
(3) Climatic Conditions.
(4) Nature of Soil.

Species of Plants.

In 1880 Wolff [1] collected all the available data on the analyses of the ash of different plants. Since that date several workers, *e.g.* Ingle,[2] Taylor,[3] Jones and Bullis,[4] have analysed pasture plants of different species. But as the mineral content is affected by factors other than the species, the data of the workers who have worked under different conditions of soil and climate, and who have harvested the samples for analysis at different stages of growth, are not comparable. To obtain reliable data it would be necessary to have all the species analysed grown under identical conditions of soil and climate, and harvested at the same stage of growth. Data of this nature are not so far available, but work on these lines is now being carried out at Aberystwyth Station, Wales. It is clear, however,

from the data on the analysis of different species by the same worker, and therefore presumably on comparable material, that the species do show natural differences in their mineral composition. The following two tables give some data selected from those obtained by one of the earliest workers and two of the most recent.

TABLE I (*a*)

PERCENTAGE OF MINERALS IN DRY MATTER IN DIFFERENT SPECIES OF PASTURE PLANTS (ANALYSED BY WAY AND OGSTON). WOLFF.[1]

	K_2O	Na_2O	CaO	MgO	Fe_2O_3	P_2O_5	SO_3	SiO_2	Cl
Alopecurus pratensis	3·36	—	·30	·10	·04	·49	·17	3·03	·35
Cynosurus cristatus	—	—	·65	·16	·01	·46	·20	2·56	·14
Dactylis glomerata	2·17	·09	·31	·12	·03	·46	·19	1·42	·54
Holcus lanatus	2·38	·23	·53	·22	·02	·51	·28	1·80	·37
Lolium perenne	2·52	·29	·73	·21	·02	·66	·39	2·05	·83
Lolium italicum	·87	·36	·69	·16	·05	·44	·20	4·12	·10
Phleum pratense	1·31	·09	·79	·28	·01	·60	·26	1·65	·12
Poa pratensis	2·28	·04	·33	·16	·02	·61	·25	1·96	·36
Trifolium pratense	1·45	·39	2·75	·94	·08	·46	·31	·32	·20
Trifolium repens	1·34	·53	2·32	·66	·10	·96	·62	·41	·29
Medicago	1·11	·10	4·67	·37	·08	·61	·29	·06	·19
Vicia sativa	2·27	·14	1·35	·35	·04	·64	·16	·08	·26

TABLE I (*b*)

PERCENTAGE OF MINERALS IN DRY MATTER IN DIFFERENT SPECIES OF PASTURE PLANTS (ANALYSED BY JONES AND BULLIS).

	K_2O	CaO	MgO	P_2O_5	SO_3
Timothy	1·55	·108	·060	·405	·187
Orchard grass	2·24	·115	·086	·350	·120
Clover, red	2·10	1·50	·393	·396	·232
Clover, alsike	2·72	1·26	·348	·513	·285
Alfalfa	2·25	1·76	·343	·556	·400
Vetch	2·06	1·12	·300	·579	·237

Cruickshank[5] has recently analysed samples of some different species collected from the same field and therefore grown under similar conditions of soil and climate. The following figures are taken from her data :

TABLE II

PERCENTAGES ON DRY MATTER.

Field:	Essiehill, Rowett Institute.		Ardmachron, Aberdeenshire.	
	Cocksfoot.	Clover.	Rye Grass.	Clover.
CaO - -	·63	1·43	·49	1·44
P_2O_5 - -	·58	·59	·80	·72
Na_2O - -	·57	·42	·33	1·03
K_2O - -	3·27	2·70	3·07	2·89
Cl - -	—	—	1·15	1·05
SO_3 - -	1·09	·80	·99	1·01
Fe_2O_3 - -	—	—	·05	·07
N - - -	1·54	2·48	2·57	3·59

It should be noted that the figures quoted in these tables are not to be taken as standards for the composition of the species referred to. Other equally reliable data not corresponding closely with these could be quoted from the literature. They are given merely to illustrate the fact that there is a natural difference in the mineral composition of different species.

The most outstanding difference is that between legumes and grasses. Legumes tend to be richer than grasses in all minerals, especially in calcium. The grasses are, however, relatively richer in phosphorus than the legumes. Thus, according to the figures in Table I (*b*), the ratio CaO : P_2O_5 is approximately 1 : 0·3 in alfalfa and 1 : 3·8 in timothy grass; and in Table II the ratio is 1 : 0·45 in clover, compared with 1 : 1·6 in rye grass and 1 : 0·9 in cocksfoot.

It is well known that the addition of clover or other legumes to grasses increases the value of the grazing. This is probably due, to some extent, to the fact that the two together in the proper proportions make a well-balanced diet. An excess of legumes, however, would tend to upset this balance by supplying an excess of calcium and probably also of protein in proportion to the other constituents, and it is doubtful whether a pasture consisting entirely of

legumes would be as nutritious as a mixed pasture. In view of the great spread of wild white clover in Britain, there might be some danger of the grasses being choked out by the clover, resulting in a pasture consisting almost entirely of clover, and therefore giving excess of those constituents in which clover is rich, and a relative deficiency of those in which the grasses are rich. It would be of interest to have some observations made on the relative value of pastures with different amounts of wild white clover, to determine the limit beyond which the increase of wild white clover becomes detrimental from the point of view of rate of growth and the health of the grazing animals.

Seasonal Variation and Stage of Growth.

One of the first workers to study the effect of stage of growth on the chemical composition of the plant was Anderson (1851)[6] (1866).[7] He analysed bean and clover plants and found that the total amount of mineral matter was greatest about the beginning of August, after which it decreased.

Sutton and Voelcker[8] noted that the total mineral matter in mixed grasses increased from June to October and Hjalmar v. Feilitzen, *et al.*,[9] found that the ash of meadow foxtail increased from June to July. Neither of these workers, however, made a detailed analysis of the ash. Lewite,[10] working on oats, found an increase in the total ash and also in potassium, calcium, and phosphorus as the plant developed. Taylor, in South Africa,[3] estimated the phosphorus in a number of different species of plants from December to March, which in the Southern Hemisphere, of course, form the summer months. He found in all cases a decrease during that period. In most cases the extent of the decrease was marked. Thus in Digitaria sanguinalis the percentage fell from 0·80 on 5th January to 0·48 on 7th

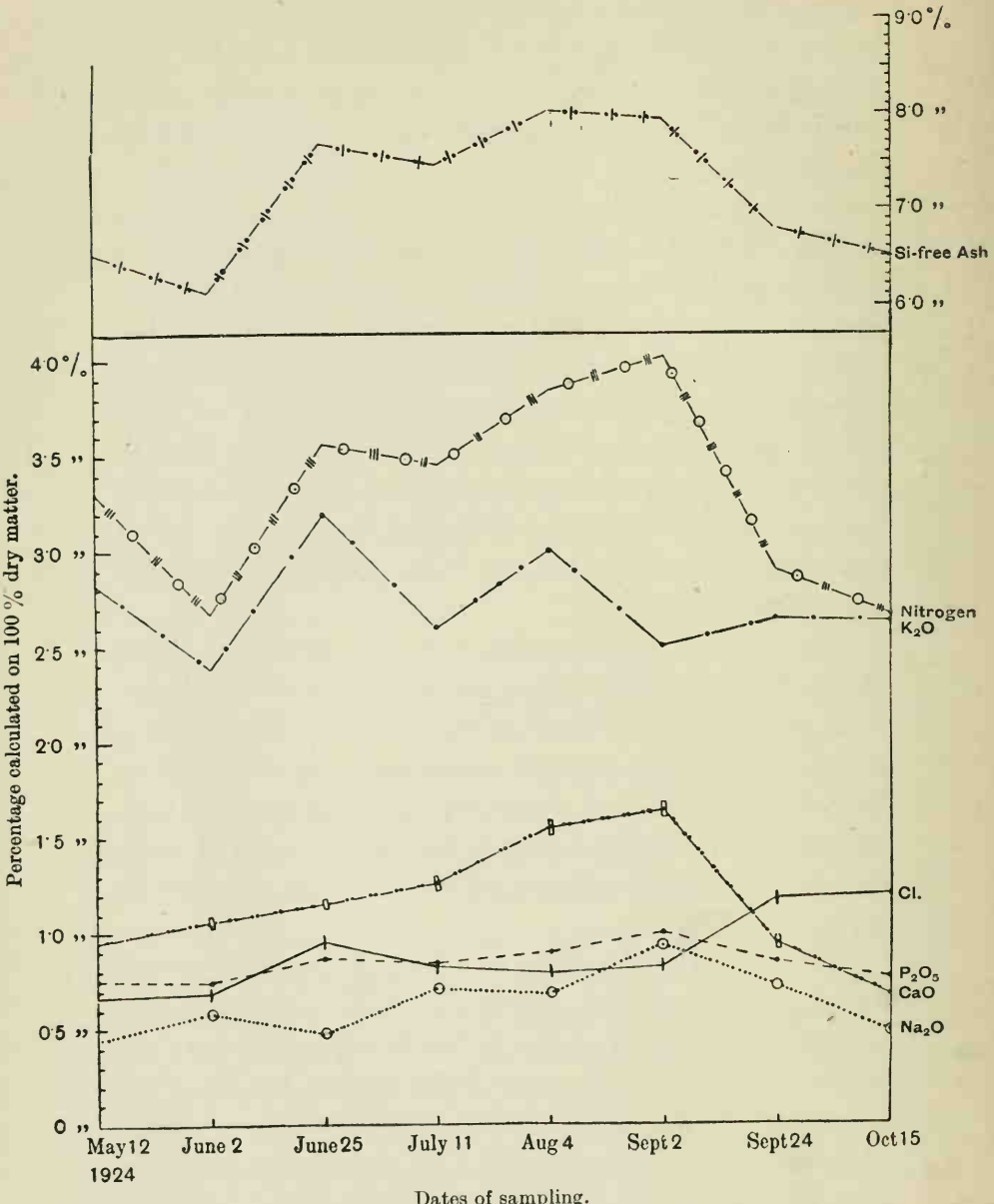
March. Theiler,[11] working on the phosphorus-deficient herbage of the South African veldt, found that the phosphorus decreased steadily from November onwards. In November the percentage found was 0·6 as compared with 0·09 in June. The latter figure, however, is complicated by drought (see below).

In England, Armstrong[12] studied the variation in composition of Leicestershire pastures, and noted that in some fields the highest percentage of phosphorus was attained in May, while in others the maximum was reached a month later.

Crowther and Ruston[13] found a tendency for the percentage of potash and phosphorus in hay to fall towards the end of the season, and Fagan and Jones[14] found that in cocksfoot and perennial rye grass, cut at monthly intervals, the percentage of phosphorus rose to a maximum and then diminished. The silica-free ash, however, did not show any regular variation.

The lack of correspondence in the results of these different workers is doubtless due to the fact that observations were made over different periods of the whole season and under different climatic conditions. As will be seen later, the percentage of phosphorus tends to decrease with drought. This possibly accounts for the difference between the results obtained in South Africa and those obtained in Europe.

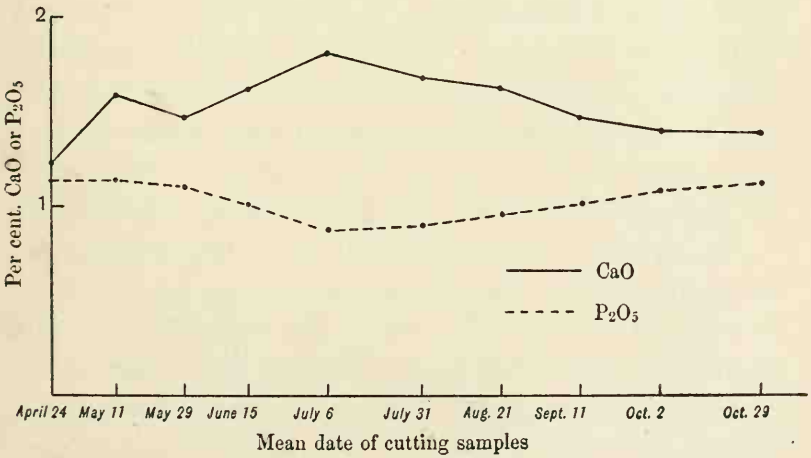
In 1923 seasonal variations were noted in the mineral composition of samples of pasture being analysed at the Rowett Institute. A review of the literature showed that our knowledge of this aspect of the subject was very incomplete. As it is one of considerable importance in connection with pasture problems, a systematic investigation was undertaken in 1924 by Cruickshank.[15] Series of samples were collected from four different fields at three weekly intervals from May to October. The analyses



Graph showing seasonal variation in mineral constituents and nitrogen.

showed a definite seasonal variation which was most clearly shown in the case of calcium, which rose to a maximum and then steadily fell. A variation, though to a less extent, was also shown by the total silica-free ash and its individual constituents. There is a rough parallelism between all the constituents, with the exception of chlorine, which tended to increase in percentage during the latter part of the season, while the other constituents were decreasing. The graph on p. 38 shows the nature of the variations obtained.

The range of variation was greater in good types of pasture than in those of inferior quality, and the period at which the maximum was reached differed in different fields. Where the pasture was heavily grazed, the percentages increased until well on in the season. Cruickshank, discussing this point, states that "the heavy grazing had apparently the effect of lengthening the most nutritive period of the life of the herbage." In the following year Woodman, *et al.*,[16, 17] at the Nutrition Institute, Cambridge, in the course of a study of seasonal variations in pastures, noted the variations in the calcium and phosphorus in pasture which was kept short by mowing. The following graph shows the results obtained :



It will be seen that the calcium curve corresponds with that obtained at the Rowett Institute, but that the phosphorus, instead of running parallel with the calcium, actually falls in the mid-season when the calcium curve is at its highest. Woodman, in an interesting discussion on the differences between the Aberdeen and Cambridge results, attributes it to the fact that owing to the close mowing at Cambridge there was an extensive spread of clover with a corresponding reduction in the amount of grass. As we have seen, the ratio of calcium to phosphorus in clover is much higher than in grass. It is probable also that the difference in climate may have had some influence, as the mid-season when the phosphorus was low was the dry season at Cambridge, when there would tend to be a decrease in the percentage of phosphorus in the pasture. The conclusion reached by both Cruickshank and Woodman is, in the words of Woodman, "although the mineral content of pastures displays a definite seasonal variation, yet the magnitude and kind of variation may be markedly different in different pastures."

Associated with the seasonal variation are the differences found in the plant at different stages of growth, and the differences in different parts of the plant. Lewite [10] studied the intake of minerals at different seasons of the year in the oat plant. He found that the greatest intake occurs at the time of sprouting and flowering, and that the amount of water used is also greatest at these times. Working with the wheat plant, Richardson [18] found that the greater part of the mineral nutrients were taken in during the early stages of growth. In general, the leaves are richer in calcium, sodium, and chlorine than the seeds (McCollum [19]). On the other hand, the seeds, as is well known, are richer in phosphorus than the leaves or stem. Fagan and Jones [14] have found that the percentage of minerals in

the leaf is greater than in the stem, although the stem is slightly richer in phosphorus than the leaf.

It is most probable that the seasonal variation is not so much associated with the season as with the stage of growth of the plant, the mineral content being highest at the stage when there is the maximum of leaf rich in active protoplasm and the minimum of fibrous supporting tissue. This is probably one of the factors involved in the fact observed by Cruickshank [15] that close grazing lengthens the period during which the herbage is of high feeding value. The grazing tends to keep the plant at the period of growth with the maximum amount of leaf and succulent stem. Close grazing or frequent cutting of course affect, in addition to the mineral composition, other properties of the pasture which determine its feeding value (Ellett and Carrier [20]; Fagan and Jones [14]; Woodman, Stewart, and Blunt [16, 17]). Many of these properties, however, such as botanical composition, are connected with the mineral content of the sward as a whole.

Climatic Conditions—Drought.

Comparatively little attention has been paid to climate as a factor in determining the composition of pastures, though it is well known that the amount of sunshine, the temperature, and the rainfall all affect the rate of growth and the rate of transpiration, and that the latter factor has an influence on the amount of salts in solution brought in by the roots of the plant. The feature which has been most studied is the rainfall. Wilms, Seelhorst, and Mayer [21, 22] showed that the ash content of plants varied with the soil moisture. Lewite,[10] in studying the effect of drought on the nutritive value of pastures, compared the calcium and phosphorus content of oat straw in a wet year with that of a dry year. In the dry year the percentage of calcium was

higher, and the percentage of phosphorus lower, than in the wet year. As the following example shows, the differences were beyond the range of experimental error :

	P_2O_5	CaO	Rainfall.
1902 - -	·372	·541	275·7
1904 - -	·222	·784	118·3

He also showed that the effect of the rainfall on the calcium content of the plant varied with the amount of calcium in the soil, being less marked in oats grown on recently limed land. The effect of drought on the calcium was evidently less marked in cases where there was sufficient lime in the soil.

Klimmer and Schmidt [23] found, by the analysis of hay, that plants take less calcium and phosphorus during severe drought, and Henry [24] states that periods of drought decrease the amount of mineral substances in the plant, particularly as regards calcium and phosphorus.

Some light seems to be thrown on the subject by the carefully recorded data of Woodman *et al.*,[16, 17] in their investigation referred to above. They state that in the period from 24th May to 29th June the amount of rain which fell " was almost negligible." In the week ending 6th July there was a slight rise in rainfall in consequence of a thunderstorm. It is seen from Graph II (p. 39) that in the period of drought, May to 6th July, there is a sharp fall in the percentage of phosphorus which was arrested in the week ending 6th July. Since in the comparable data of the following year, which are not complicated by drought, there was no corresponding fall in the percentage of phosphorus, Woodman's figures seem to support the conclusion of Lewite [10] that the percentage of phosphorus is reduced by drought.

The scanty evidence available seems to indicate that drought has the effect of decreasing the percentage of phosphorus. There is not sufficient reliable evidence, how-

ever, to determine whether it seriously affects the percentage of any of the other constituents. As there are extensive areas of grassland with a low rainfall, the effect of drought on the chemical composition of the pasture plants warrants further investigation.

Apart from the effect on the botanical and chemical composition of the herbage, the application of fertilisers to poor soils probably affects the rate of loss of water from the soil. In East Africa the writer has noted that in drought the pasture with a high percentage of mineral matter, and therefore presumably growing in rich soil, remains green longer than pasture with a very low phosphorus content, and therefore presumably grown on phosphorus-poor soil. Further, the former responds to rain more quickly than the latter. At the Waite Institute in South Australia, it has been noted in pot experiments that transpiration of water by pasture plants from phosphorus-poor soil is greater in some cases to the extent of about 30% than that of plants grown in the same soil with super-phosphate added. It looks as if the enrichment of the soil conserved the soil moisture. If this result be confirmed in field plots, it will afford an additional reason for applying phosphates to phosphorus-poor soils in areas with a low rainfall. It is a result of great economic importance to the pastoral industry in semi-arid regions (Richardson [25]).

Reference may be made here to the effect of irrigation, a subject which has been recently treated in a lucid article by Keen.[26] In addition to supplying water, irrigation also alters the composition of the soil by the gradual accretion of soil constituents, which in some cases are beneficial, but more often harmful. This affects the mineral composition of the plant (see next section), and therefore the influence of irrigation in this direction cannot be ascribed entirely to the water.

Chavan,[27] working at Lausanne in Switzerland, found that irrigation affects the flora, the grasses being increased at the expense of the legumes, *e.g.*:

	Graminiae.	Legumes.	Miscellaneous.
Irrigated - -	80·21	0	19·79
Dry - -	63·45	15·40	21·15
Irrigated - -	87·26	0	12·74
Dry - -	74·57	18·08	7·35

The chemical composition of the hay was also altered, *e.g.*:

	Irrigated Meadows. %	Dry Meadows. %
P_2O_5 - - -	0·729	0·457
K_2O - - -	3·306	2·895
CaO - - -	0·943	1·002
MgO - - -	0·474	0·381
SO_2 - - - -	0·649	0·682

It will be seen that there is a marked increase in the percentage of phosphorus and also in potassium, but little change in calcium.

Fischer,[28] in tests with the same species of plant, viz. alfalfa, found that frequency of watering by irrigation affects the percentage of potassium, the effect on the phosphorus not being so marked in this case.

	P_2O_5	K_2O
Control Plot - -	·595	1·579
Watered 5 times -	·564	1·760
Watered 8 times -	·676	2·199

These results seem to indicate that, as might have been anticipated, irrigation affects the mineral composition of the pasture through the increase in soil moisture, the difference between irrigation and dry being somewhat similar to that found between after rain and after drought.

Nature of Soil—Application of Fertilisers.

The general principle that the mineral composition of the mixed herbage tends to be a reflection of the available

minerals in the soil is illustrated by the difference, shown in Table IV (p. 13), in the composition of pasture from poor unimproved hill soils and from enriched cultivated soils. The principle is definitely established by data collected by many different workers. Roloff [29] gives the following figures, showing the beneficial effect of applying bone meal to poor soil :

In 100 Parts of Hay.

	Unmanured Meadow.	Manured Meadow.
P_2O_5 - - -	0·23	0·51
CaO - - -	0·81	1·16

Bonnetat and Touchard,[30] studying the effects of phosphatic manures, found that the application of these to the soil was followed by an increase in the percentage of phosphorus, in one case from 0·297 to 0·494, and in a second case from 0·30 to 0·53. Paturel [31] applied slag and potash to the poor prairie land of the Bressane region in France and found an increase in the percentage of calcium and phosphorus in the herbage, *e.g.* :

	Control.	Slag.	Slag plus Kainit.
Mineral Matter %	6·35	6·41	8·11
P_2O_5 - - -	0·26	0·38	0·47
CaO - - -	1·09	1·23	1·6

Even more striking results have been obtained by Richardson,[32] who carried out extensive tests on the depleted soils of Victoria in Australia, on the effects of the application of phosphates and lime. The following table shows the effects of the addition of these mineral fertilisers to a soil poor in phosphorus and lime :

Fertiliser applied.	Hay. Cwts.	Composition of Herbage % Dry Matter. N.	P_2O_5	CaO
No Manure - - - -	23·2	1·46	·27	·60
1 cwt. Superphosphate - -	43·7	2·28	·59	1·47
1 cwt. Superphosphate plus 10 cwts. Lime - - - -	62·1	2·20	·46	1·44

The effect of the application of the mineral fertiliser is most marked in poor soils. This is well brought out in some tests carried out at the Rowett Institute. The following table (Godden [33]) shows the effect of lime and phosphates on (*a*) very poor moorland soil and (*b*) cultivated soil.

Fertiliser applied.	Poor Moorland Soil.		Cultivated Soil.	
	CaO	P_2O_5	CaO	P_2O_5
Nil (control)	·59	·29	1·16	·96
Lime	·77	·30	1·37	·92
Superphosphate	·94	·71	1·16	·93
Lime plus Superphosphate	·98	·73	1·56	·92

It will be seen that in the poor soil the addition of the phosphate increased the phosphorus content of the herbage by three times, whereas in the cultivated soil the phosphorus content of the pasture, which was already high, was not increased.

Results of the same general nature as those referred to have also been obtained by Hébert and Truffaut [34]; Barnes [35]; Gile and Ageton.[36]

There are two factors concerned in this correlation between soil and herbage. A rich soil favours the spread of those species which are naturally rich in minerals and also tends to enrich the individual plant whatever its species.

The influence of the first factor is shown by Paturel [31] and Richardson,[32] who did a botanical survey in their tests on the application of fertilisers. These workers found that one of the chief effects of the fertilisers was the modification of the flora in the direction of increasing the leguminous plants.

Extract from Paturel's Data.

Control.	Fertilised.
20% leguminous	62% leguminous
31% useless grasses	8% useless grasses

Extract from Richardson's Data.

Fertiliser applied.	Percentage in pasture. Grasses.	Clovers.	Weeds.
No Manure - - - - - -	64·7	14·3	21·0
1 cwt. Superphosphate - - -	18·0	74·8	7·2
1 cwt. Superphosphate plus 10 cwts. Lime	21·0	74·3	4·7

It is seen that the application of the phosphate to the soil alters the vegetation in the direction of increasing the clover plants at the expense of the grasses and weeds.

With regard to the effect on the individual plant, Malaguti and Durocher [37] found that the percentage of calcium in the ash of clover growing on calcareous soils was 43·32 compared with 29·72 in plants growing on non-calcareous soils. Kincaid [38] showed that European grasses grown on phosphorus-poor soils in Australia had a lower phosphorus content than the same kinds of grasses grown in Europe. It is possible, however, that the phosphorus content of the plants grown in Australia may have been affected to some extent by the lack of moisture in the soil.

Godden [33] made a systematic study of the effect of different fertilisers on red clover. He did his tests on plots which were specially prepared, so that the composition of the soil to begin with was uniform in all the plots. The control plot received a fertiliser mixture supplying calcium, magnesium, sodium, potassium, iron, phosphorus, chlorine, sulphur, and lime, and from each of the other nine plots one ingredient was omitted. The following figures, taken from his tables, show that the same species of plant is affected by the composition of the soil:

	Complete Fertiliser.	Omitted from Complete Fertiliser. Calcium.	Phosphorus.	Potassium.
CaO % -	2·41	1·94	2·25	2·84
P_2O_5 % -	·65	·62	·63	·58
K_2O % -	5·99	6·42	5·98	3·53

It will be seen that in the plot with lime omitted the percentage of calcium was lower than that in the plot with

the complete fertiliser containing lime. The effect of the omission of potassium is even more marked. The omission of phosphorus, however, had comparatively little effect.

In a field test, on a soil deficient in phosphorus, Richardson [32] obtained a much more marked effect, as is shown by the following figures :

Nature of Herbage.	% P_2O_5 in the Ash. Unmanured.	Manured with Phosphates.
Grasses - - -	4·79	9·67
Clovers and Trefoils -	4·81	8·59
Weeds - - -	3·96	8·02
Mean - -	4·52	8·76

These figures of Richardson's show that application of phosphate doubled the percentage of phosphorus in the three types of plants. It is interesting to compare this result obtained on a deficient soil with that obtained by Godden on a good soil. The comparison illustrates the principle that the effect of any fertiliser is in proportion to the degree of deficiency of the soil in the element it contains.

From the results of these various investigations, it is obvious that the mineral composition of pasture is affected by the composition of the soil on which it grows, and that the alteration of the composition of the soil by the application of fertilisers increases the mineral content of the pasture, the increase being most marked in poor soils. The increase is due partly to the fact that the individual plants are enriched, and partly to the fact that the fertilisers promote the growth and spread of species of plants which are naturally richer in minerals.

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CHAPTER IV

CONDITIONS UNDER WHICH DISEASES DUE TO DEFICIENCY OF MINERALS IN PASTURES OCCUR

The mineral requirements of young animals depend upon their rate of growth. The faster the growth, the richer must the diet be in all food constituents, including inorganic salts, which are needed as constructive material for the formation of new tissue. This is strikingly illustrated in a comparison of the average rate of growth of the young of different species with the concentration of mineral matter in the milk of the species.

Modification of Table by Pröscher and Abderhalden.[1]

Species.	Time in days to double weight after birth.	The Milk of the Species contains : Ash %	Ash in grams per 1000 calories.
Man - - -	180	0·25	3·7
Cow - - -	47	0·72	10·5
Pig - - -	14	1·03	10·9
Rabbit - -	6	2·50	15·0

It is seen that in the milk of the faster growing species, not only is the percentage of ash higher, but the proportion of ash to energy-yielding constituents is also higher. The rate of growth of cattle in the natural state is slow compared with modern standards, and the amount of milk produced by cows is limited to that required by the calf. The improvement in cattle through selective breeding has produced types with a greater rate of growth and a greater capacity for the production of milk. Modern cattle grow at double the rate of the type from which they originated

and they reach maturity in about half the time. The domestic cow, under good conditions of feeding, has her first calf when about three years old. "Native" cattle breed much later. Thus in Nigeria the cows do not have their first calf until they are about six years old (du Toit [2]). Milk production has also increased. In the natural state cows do not produce more than 200 to 300 gallons in a lactation period, whereas in modern dairy breeds the yield is commonly from 700 to 1000.

This improvement in the breed has been associated with an improvement in the pastures. Cultivated pastures are much richer in minerals than those grown on natural unimproved soils (see Table IV, p. 13). Without the improvement of the pastures, improvement of the breed would have been impossible.

When animals of an improved type, bred on a mineral-rich pasture, are transferred to a district with poor pastures, the low mineral content of the poor pastures is liable to be insufficient to support the rate of growth or the capacity for milk production, and consequently malnutrition, due to deficiency of minerals, is likely to occur. As a matter of fact, in new countries diseases associated with deficiency of minerals have occurred under these conditions. It is commonly found that when high grade bulls are imported to grade up native cattle, the mortality increases with the grading up, *i.e.* as the rate of growth of the cattle increases. This has occurred in many parts of the British Empire where attempts have been made to improve the breed without ensuring that the feed was sufficient to maintain an improved breed.

Another set of conditions under which deficiency diseases may arise is when over a period of years a grazing area has been depleted of minerals through the removal from the area, of animals or animal products, such as milk,

without any compensating return to the soil. Under these conditions the mineral content of the pasture decreases. If the forces of nature were left to operate, there would be a gradual elimination of the faster-growing types; with the evolution of a type with a slower rate of growth adapted to the impoverished pastures. But by selective breeding and importation of new blood, the quality of the stock is maintained or even improved, and consequently there is an increasing gap between the requirements of the animal for minerals, and the supply of these in the pastures.

There are in the literature a number of instances of depletion of pastures. Munro [3] reports that in the Falkland Islands sheep have been reared and exported for about forty years without any return to the soil to replace the minerals removed. During the last twenty years it has become increasingly difficult to rear lambs. The other animals are also deteriorating. After a few generations the progeny of imported horses become reduced to the size of ponies, and cattle which are progeny of several generations of locally-bred animals are small, averaging about 500 lb. when fat. It is obvious that nature is trying to evolve a type whose rate of growth and ultimate size is adapted to the nutritive value of these pastures, which have been shown recently to be very low in mineral content (Godden [4]).

Richardson [5] has recently called attention to the effects of depletion in Victoria. He has estimated that the soil of Victoria has been depleted to the extent of about 360,000 tons of phosphoric acid during the last sixty years, through the removal of phosphates in the exported meat, meal and other animal products, and that nearly 2,000,000 tons of superphosphate would need to be added to the pasture lands to restore them to the condition they were in about 1860. He attributes malnutrition in stock to the resulting deficiency of phosphorus in the pastures.

In our own country this process of depletion has been going on, especially in hill pastures, for many years, and it is probable that the recognised decrease in the value of hill pastures in certain areas, and the accompanying increase in the diseases and mortality of sheep, is associated with the gradual process of impoverishment of the pasture.

There is some evidence that the same process of depletion has taken place in India. During the years 1920-25 over 520,000 tons of bones have been exported without any compensating return being made to the soil. The evidence presented before the recent Commission on Agriculture in India shows that there has been in recent years a marked deterioration in the cattle.

This question of depletion of pastures is one of great economic importance. It has not been sufficiently realised that accompanying the visible export of carcases, milk, wool, cheese, hides, bones, etc., there is an invisible export of fertility.

From the foregoing considerations it is evident that malnutrition due to deficiency of minerals in pasture would be most likely to occur in old countries on uncultivated grazings to which no return had been made to compensate for the produce taken off them, or in new countries where the native stock had been graded up without a corresponding grading up of the pasture. It will be seen in the following chapter that it is under these conditions that deficiency diseases have occurred.

The outstanding symptoms of these diseases are those associated with impaired powers of locomotion and lesions of the bones. The affected animals frequently suffer from pica or depraved appetite. Accompanying or preceding these gross signs of disease there are always signs of general malnutrition, such as a rough staring coat, and a degree of emaciation. In young animals growth is stunted, and in

full-grown females the breeding capacity is affected and the milk yield low. Calves born are weak, and frequently the placenta is retained. The animals most liable to be affected are the heavy milking breeds (Klimmer and Schmidt [6]; Kleinpaul [7]; Friedberger and Fröhner [8]).

The characteristics of these diseases are similar to those which have been described as developing in animals under experimental conditions, when fed on rations deficient in one or more of the essential mineral constituents.

The etiology of these nutritional diseases has been studied by a number of workers. In most cases attention has been directed to the herbage, hay, or fresh pasture in the belief that the chief etiological factor was either deficiency or excess of some mineral element. Indeed, our knowledge of the mineral content of pastures of low nutritive value has been derived from these investigations.

The papers dealing with the subject fall naturally into territorial groups. In reviewing the literature in the subsequent chapters, it will be convenient to follow this grouping, beginning with the continent of Europe where the earliest work was done.

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CHAPTER V

DEFICIENCY DISEASES IN GRAZING ANIMALS IN EUROPE

Diseases characterised by pica and softening or rarefaction of the bones with accompanying malnutrition have been recorded in districts in Germany, Hungary, Belgium, Bohemia, France, and Norway under various names which are usually descriptive of one of the chief symptoms, *e.g.* " Hinsch," " Semper," " Darr," which all mean emaciation or wasting away, " Lecksucht " (licking disease, pica or depraved appetite), and " Knochenbrüchigkeit " (osteomalacia or " brittle bones "), and " Osteite " (inflammation of the bones). Descriptions of these pathological conditions are given by various veterinarians, *e.g.* Friedberger and Fröhner,[1] Ostertag and Zuntz,[2] Hutyra and Marek.[3] A short account of the symptoms sufficient for the present purpose has been given in the preceding chapter.

Pica and brittle bones or osteomalacia have been regarded by some workers as separate diseases. Most workers, however, regard the two conditions as merely different manifestations of the same disease. They occur in the same areas, and animals with pica frequently develop bone lesions and vice versa. There seems little doubt that the two conditions are part of the same complex of symptoms, the pica being merely the manifestation of an instinctive craving for some substance, the deficiency of which is the cause of the lesions in the bones and the accompanying symptoms of malnutrition. The extent to

which the pica develops varies, of course, in different animals. In some it appears before there are any obvious symptoms of lesions in the bones. In others the pica symptoms are much less marked and may not be very obvious even when the bone lesions are severe. It is obvious, of course, that both bone lesions and pica may be produced by causes other than those to which the diseases under consideration here are to be attributed, in which case, of course, no correlation between the two sets of symptoms is to be expected. In the present account they are considered together merely as prominent symptoms of the same deficiency disease, and as being due to the same primary cause.

References to pica and brittle bone are found in the literature from the middle of the seventeenth century. Cammerarius (1665)[4] refers to pica-ridden farms in the Black Forest. Accounts of brittle bone are given by Hinker (1780),[5] Gleditsch (1787),[6] Bohlmann (1823),[7] and Laist (1837).[8] The attention of these early writers was directed to this disease on account of the heavy losses in cattle suffered in certain districts. These losses have continued even in modern times. Thus, for example, Winkler (1890)[9] states that in the Grafenau district "brittle bones" cause more loss than all the other diseases put together, and in Burgsteinfurt, according to König and Karst (1922),[10] half of the calves suffer, and of these one third die.

These economic losses have stimulated investigations to determine the cause of the disease. A few workers, *e.g.* Petrone,[11] Morpurgo,[12] regarded bacteria as the causal agents. Lemke,[13] however, showed that the condition was not infectious. Cattle from healthy farms, if put amongst animals suffering from the disease, did not develop the symptoms provided their food was unchanged, but if they were given the same food as the sick animals, the symptoms ultimately appeared. On the other hand, sick animals, if

fed on fodder from a healthy farm, recovered, even if kept in the same environment in which the disease occurred. It is probable that there is frequently a bacterial invasion, especially in later stages of the disease when the resistance of the animals to infection is lowered, but there is little evidence to suggest that bacteria are the primary cause.

The great majority of workers have carried out their investigations on the assumption that the disorders were nutritional in origin, and have directed their efforts towards finding toxic substances or deficiencies of essential nutrients in the food or water. The water was suspected by Dèle,[14] who investigated a number of cases which occurred near Anvers in Belgium in 1833. No harmful substance to which the disease could be attributed was found in the water, but it was noted that it contained no lime salts. Roloff (1866) [15] suggested deficiency of calcium in the drinking water as a cause of the disease, and Dobusch (1877),[16] who investigated a number of cases at Hohenfurt in Austria, also directed his attention to the drinking water, which he found to be lacking in salts. He records a case in which animals recovered when the source of the drinking water was changed to a brook rich in salts. While it is true that certain waters are so rich in mineral salts that they make a substantial contribution to the requirements of the animal for certain elements, the amounts obtained from ordinary water are small compared with the amounts obtained from the food. It is probable, however, that too little attention has been paid to this aspect of nutrition. Water rich in mineral salts may have a greater effect on nutrition than is supposed. In some cases the effect may be beneficial by supplying mineral salts required, and in other cases harmful through the presence or excess of certain salts.

As the disease is associated with definite districts, the condition of the soil in those districts has received a good

deal of consideration. Various types of soil on which the disease occurs have been described (Zundel [17]; Vernant [18]), and the soil in affected areas analysed (König and Karst [10]; Westermann [19]). These investigations on the nature of the soil bring out no single common factor either physical or chemical to which the disease can be ascribed. The only general conclusion which can be drawn from the results of work on the soil is that in the areas where the disease is prevalent the soil is poor in some of the constituents required for fertility, or is of such a nature that there is either excess or deficiency of water.

The effects on the incidence of the disease of alteration of the condition of the soil have been noted by several writers. Paugoué [20] states that the disease increases with impoverishment of the soil and decreases with its improvement. Neyen [21] notes that in Wurtemberg the disease has disappeared since the land was drained. The application of fertilisers, *e.g.* lime, slag and kainit was found to act as a preventive (Liénaux and Huynen [22]; Popp [23]). Recently Tuff,[24] who carried out systematic investigations on the disease in Scandinavia, states that in consequence of the manuring of the land in the good agricultural districts there has been a great decrease in the incidence of the disease since 1880. Similar beneficial effects of manuring have been noted in countries outside Europe (see pp. 78, 98). On the other hand, the application of manure to the land is not invariably followed by the disappearance of the disease. In the Oldenburg district, Germany, manuring with " Thomasmehl " (basic slag) seems to have been followed by an increase in a form of malnutrition accompanied by " pica " to which the term " Thomasmehlseuche " has been given (Popp [23]; Kleinpaul [25]). In some districts manuring with potash seems to have had a somewhat similar result (Ostertag and Zuntz [2]).

Most of the investigators have sought for the cause of the disease in the nature of the herbage. Some searched for poisonous plants to which the disease could be attributed. Thus Haubner [26] suggested that Molinia caerulea caused "brittle bone" when it formed a big proportion of the food, but Müller,[27] who carried out an extensive botanical survey at Boker Heath in Lippstadt, where "brittle bone" was rife, found that though the better meadows had a higher percentage of sweet grasses and papillionacae than the meadows associated with the disease, there was no single plant to which the disease could be attributed. There is in the literature no convincing evidence that toxic substances present in plants are causal agents.

The great majority of the workers who have carried out systematic investigations on the subject, are agreed that the cause of the disease is to be found in the mineral composition of the herbage, and that soil conditions and species of plants are involved only in so far as they affect the mineral content of the pasture or hay. As the diseases are more prevalent in the winter and early spring, when the cattle are fed indoors on hay, attention was directed more to the chemical composition of hay than of green pasture.

In the course of these investigations masses of analytical data on the chemical composition of hay have been accumulated. It is unnecessary to quote these in detail. It will be sufficient to give an indication of the nature of the results obtained and the conclusions reached by a number of the writers, and to quote some data showing the difference between the composition of hay from districts in which the diseases occur, and that from neighbouring healthy districts.

In 1816 Nessler [28] analysed samples of hay from pica districts. He found it to be very low in sodium, normal hay containing ten times as much as that which produced the disease. He considered deficiency of sodium to be one, but

not the only cause of the disease. He advised adding common salt to the animals' ration. In a later paper [29] on brittle bone, he refers to the influence of drought in rendering pasture plants poor in mineral salts and thereby increasing the incidence of the disease.

Neyen (1863) [21] emphasised the importance of the composition of the soil as a factor in the causation of brittle bone. He quotes analyses of soil where the disease occurred, to show that it is poor in phosphates, and also gives figures to show that the acid-soluble part of the ash of hay grown on the soil is less than that of good hay. He points out the importance of soil moisture on the mineral content of the plant, which is affected both by deficiency following drought, and by excess in water logging. He states that in several parts of Wurtemburg in the Zurich Canton in Switzerland, where the disease had been prevalent, it disappeared after the land had been drained. He presumed that the beneficial effect was due to the resulting modification in the mineral composition of the herbage.

Roloff,[30, 31, 32] who regarded "licking disease" as merely a first symptom of brittle bone, attributed the cause to deficiency of lime salts in the hay. He points out that this accounts for the fact that it was especially prevalent in cows during lactation or pregnancy when the need for these salts is greatest. He gives the following figures for the analyses of "harmful" hay and normal hay in Westphalia where the disease was widespread:

Analyses of Hay.	Hay from the harmful meadow. %	Normal hay. %
Potash	1·42	2·00
Magnesia	0·24	0·39
Lime	0·70	0·90
Phosphoric acid	0·26	0·48
Sulphuric acid	0·46	0·40
Silicic acid	1·92	2·19

From the above figures and also those quoted below it seems probable that in this case deficiency of phosphorus was more important than deficiency of calcium. He found that sick cows were cured by the administration of bone meal, but this would supply phosphorus as well as calcium. It is interesting to note here that Roloff at this early date (1866) studied the correlation between the stage of growth of the plant and its protein and mineral content, and quotes figures to show the high protein and ash content of young plants (red clover). He also carried out tests to determine the effect on the composition of the plant of the application of mineral fertilisers to the soil. His results with bone meal are in accordance with the more recent work, *e.g.*:

In 100 Parts of Hay.

	Unmanured meadow.	Manured meadow.
Phosphoric acid - - -	0·23	0·51
Lime - - - - -	0·81	1·16

Müller[27] began his investigation from the botanical point of view (p. 60), and came to the conclusion that deficiency of phosphorus was the important factor. He quotes instances of the disappearance of the disease at Boker Heath, Lippstadt, after the feeding of bone meal. Morgen[33] found that hay which caused brittle bone is very poor in both lime and phosphorus, one sample of hay causing the disease containing only 0·37% CaO and 0·20% P_2O_5. He notes the close correlation between chemical and botanical composition of the hay, that richer in lime being better hay botanically.

Soxhlet,[34] who investigated "licking disease" at Munchen, attributed it to the lack of the constituents necessary for the development of calves. He regarded lack of phosphorus as the chief factor.

Klimmer and Schmidt[35] investigated brittle bone which

was prevalent in the neighbourhood of Dresden in 1904, a year which had a long season of drought. They ascribe the disease to deficiency of calcium and phosphorus, the percentages of which were lower in harmful than in normal hay. These writers give a review of the literature on the subject, and quote analytical data of previous workers to show the difference between the calcium and phosphorus content of hay causing the disease and that of normal hay.

HAY CAUSING "BRITTLE BONE."

100 PARTS OF DRY MATTER CONTAIN:

According to:	CaO	P_2O_5
Karmrodt	0·68	0·22
,,	0·90	0·23
Stohmann	0·70	0·26
Wolff	0·63	0·26
Morgen	0·37	0·20
,,	0·67	0·26
Stutzen	1·52	0·29
Nessler	—	0·49
,,	—	0·35
,,	—	0·28
,,	—	0·27
,,	—	0·28
Germain	0·30	—
Roloff	0·70	0·26
Dircks' Forest Hay	0·19	0·155
,, ,, ,,	0·28	0·14
,, ,, ,,	0·28	0·13
Kellner	—	0·22
Meadow Hay	—	0·26
Kellner	—	0·28
Temporary Ley	—	0·28
Klimmer and Schmidt:		
Plateau	0·50	0·27
Valley	0·35	0·32

Normal Hay.

100 Parts of Dry Matter Contain:

According to:	CaO	P_2O_5
Hoffmeister - - - -	1·43	0·81
Weiske - - - - -	1·12	0·55
Karmrodt - - - -	0·95	0·43
Johnson - - - -	—	0·57
Wolff - - - - -	1·43	0·43
„ - - - - -	1·06	0·58
„ - - - - -	1·60	0·48
V. Gohren and Langer - -	—	0·55
Wolff - - - - -	1·11	0·50
„ - - - - -	1·18	0·46
Stutzen (according to Bongartz)	0·95	0·42

The above figures show that, compared with normal hay, all hays which cause brittle bone are very poor in phosphorus, and many of them are also very poor in lime. On the whole, phosphorus is more uniformly low than calcium, suggesting that deficiency of phosphorus is the most important factor in causing the disease.

Ostertag and Zuntz [2] found that the greatest anomaly in the poor meadow hays which cause malnutrition accompanied by pica was the low sodium : potassium ratio. They suggested that excess of potash was the cause of the disease, and that this explained its occurrence on meadows where, owing to the use of potash manures, the potash content of the hay was very high. Later Zuntz [36] emphasised the importance of the proportions of the minerals to each other and suggested that the evil effects of poor meadow hay were probably due to the lack of proper balance of the minerals. He regarded the ratios of sodium and potassium, of calcium and phosphorus, and of acids and bases as being specially important. The following figures taken from Zuntz's tables show the difference in the calcium, phosphorus, sodium and potassium content of good hay and that causing the disease :

PERCENTAGE OF DRY MATTER.

	CaO	P_2O_5	Na_2O	K_2O	$Na_2O : K_2O$
Hay "causing Brittle Bone" - -	0·693	0·380	0·082	1·762	1 : 21·4
Less Injurious Hay	0·919	0·535	0·162	0·843	1 : 5·2
"Normal" Hay -	1·416	0·496	0·386	1·422	1 : 3·7

It will be noted that in the hay "causing brittle bone" in addition to the abnormal sodium : potassium ratio emphasised by Zuntz, the percentages of both calcium and phosphorus are low. In the light of the table given by Klimmer and Schmidt,[35] it is probable that deficiency of these is as important, if not more so, than the abnormal ratio.

Popp [23] studied "Thomasmeal sickness," which is closely similar to and probably identical with "licking disease." He analysed both soils and hay and came to the conclusion that the disease was due to deficiency of bases, chiefly of lime, in the hay. He advised the administration of carbonate of lime to cattle. He emphasises the importance of the ratios of the minerals to each other and gives data on the analyses of hay in which the ratio of $CaO : P_2O_5$ varies from 100 : 339 to 100 : 51.

Tuff,[24] who investigated osteomalacia in cattle in Norway, came to the conclusion that it was due to insufficiency of minerals in the fodder, the hay from marshes and forests being lacking in both phosphorus and calcium. He quotes the following data to show the difference in the calcium and phosphorus content of disease-causing and normal hay :

NORWEGIAN HAY.

Area affected.		Area non-affected.	
CaO %	P_2O_5 %	CaO %	P_2O_5 %
0·460	0·150	0·880	0·440
0·185	0·155	0·410	0·560
0·279	0·143		
0·287	0·129		
0·330	0·270		

In addition to those which have been referred to here, there are a number of other workers whose investigations or writings on the subject are of interest and repay reading in the original. The conclusions which they reach, however, are not markedly different from those quoted above. Thus, Alwens [37] attributes diseases affecting the bones to lack of protein, calcium and phosphorus in the hay. König and Karst,[10] who investigated the effect of manuring on the mineral content of the plant in connection with pica, concluded that the condition was due, not to lack of any one mineral, but to deficiency of several. Marek,[38] who ascribes diseases with bone lesions to calcium deficiency, combined with a luxus consumption of protein which upsets the acid-base equilibrium, advocates the administration of lime and phosphorus and a preponderance of alkali over acid in the diet. He also points out the beneficial effect of sunlight and exercise.

Consideration of the results of all the different investigators leads to the conclusion that the chief factor in the disease in cattle of which pica and bone lesions are the most obvious gross signs, is some deficiency in the mineral content of the herbage. It is not, however, the same substance which is deficient in every case. Calcium and phosphorus, the two minerals required in greatest amounts, are probably those which are most frequently deficient. Deficiency of phosphorus is likely to occur on the light sandy soils, and in view of the effect of drought on the phosphorus content of the plant (p. 42) deficiency of this element would appear to be the main factor in the epidemics which occur in dry years, such as 1904. On peaty soils deficiency of calcium is probably the most important factor.

The ratio of the different minerals to each other is undoubtedly of importance, as excess of individual minerals in some cases affects the absorption and assimilation of

others. The abnormal ratio which has received the greatest amount of attention is the ratio of sodium : potassium. Bunge,[39] on the ground of rather limited experimental data, concluded that excessive intake of potassium salts impoverished the organism in sodium and chlorine. The work of Richards, Godden and Husband [40] at this Institute, however, has not confirmed Bunge's conclusion. They find that while the increase of potassium salts in the ration caused an immediate increase in the urinary excretion of chlorine, the increased excretion is only temporary, and is followed by a compensatory decrease. The continued high intake of potassium has little or no effect on the excretion of chlorine. They found, however, that excess of potassium led to a decreased assimilation of nitrogen, phosphorus and calcium, and is therefore harmful. The evil effects would be most evident with rations deficient in these constituents. The pastures in which Zuntz [36] found a high potassium : sodium ratio were poor in these constituents. It is probable that the wrong ratio of potassium : sodium accentuates the effects of the deficiency.

On the whole the wrong balance of minerals due to excess of one element appears to be of less importance than deficiency. It is probable that in the cases where sodium chloride tends to cure pica, the result is due as much to the fact that it makes good a deficiency of sodium or chlorine as to the adjustment of the potassium : sodium ratio.

In almost all cases the deficiency disease investigated by these German workers was worst in winter and early spring, when the animals were fed indoors on hay. In addition to the fact that hay is more deficient in minerals than young growing pasture (Fleischmann),[41] the absence of sunlight would be an important etiological factor. It is now a well-established fact that ultra-violet irradiation increases the percentage absorption and utilisation of what-

ever calcium and phosphorus are present in the diet (Orr *et al.*[42] Hart *et al.*[43] Henderson [44]). The lack of sunlight would therefore accentuate the results of deficiencies in the fodder.

In concluding this review of the European literature, it is of interest to note the achievements of the early workers. They traced the cause of pica and brittle bone with the accompanying pathological conditions to the abnormal composition of the hay, and showed how it could be prevented or cured by the administration of substances such as bone meal or common salt, which were rich in the elements deficient in the hay. In addition, they elucidated the more important factors that affect the mineral content of the herbage, *e.g.* stage of growth of pasture plants (Roloff, 1866 [15]), soil moisture (Neyen, 1863,[21] Nessler, 1873 [29]), and composition of soil, especially as affected by application of mineral fertilisers (Paugoué, 1854,[19] Neyen, 1863,[21] Nessler, 1873 [29]). Modern workers are doing little more than exploiting the discoveries made by these pioneer investigators.

Great Britain.

Gross forms of malnutrition due to deficiency of minerals in pastures or hay are not so common in Britain as in some of the European countries. The few papers found in the English literature deal chiefly with localised conditions and form a group rather apart from the continental literature. It is more convenient, therefore, to deal with them here separately.

A disease locally known as "scouring" occurs on the so-called "teart" or "tart" lands of Somersetshire, Gloucestershire and Warwickshire. It specially affects dairy cattle during the summer months. The cause of this condition has been sought for in the soil by Clarke,[45] Voelcker [46] and Gimingham.[47] Clarke and Voelcker noted

that it occurred on soil with an impervious subsoil, in which the water contained enormous quantities of mineral salts with a considerable proportion of aperient saline substances. They found that the hay from scouring land contains more mineral matter than hay from non-scouring land.

The following table, in which Voelcker's data are calculated as percentages of dry matter, shows the mineral content of hay off scouring land compared with the hay off sound land :

	Hay off sound land.	Hay off " scouring " land.
K_2O - - - -	1·89	3·44
Na_2O - - - -	·34	·091
CaO - - - -	·86	1·25
MgO - - - -	·23	·28
Fe_2O_3 - - - -	·024	·090
P_2O_5 - - - -	·33	·65
SO_3 - - - -	·31	·38
SiO_2 - - - -	2·66	2·76
Cl - - - -	·69	1·36

The only striking feature is the high percentage of potash and the relatively low percentage of sodium in the scouring hay.

Gimingham analysed the fresh herbage but found nothing to which the scouring could be attributed. He gives only the percentages of calcium and magnesia, which are both lower in the herbage of " teart " land than in that of sound land.

If this condition be due to an abnormal mineral content of the pasture and drinking water, it would appear from Voelcker's results to be caused by an excess rather than deficiency of minerals.

A sheep disease known as " pining " or " vinquish," described by Hogg " The Ettrick Shepherd," [48] occurs on certain well-defined areas on the hills in the South of Scotland. The most marked symptoms are emaciation and anaemia. The condition has recently been investigated by

McGowan and Smith.[49] Change of pasture cures the condition, and this procedure is regularly employed as a preventive. The sheep are removed yearly for a few weeks, after which they can be returned to the affected area and will remain healthy for the rest of the year. This disease is very similar to, if not identical with, "bush-sickness" in New Zealand and "Nakuruitis" in Kenya (pp. 81, 95). Aston and his co-workers[50] have found that the "bush-sickness" is caused by deficiency of iron in the pasture, and "pining" may be due to the same cause. The disease, however, may occur on soils rich in iron; but there may be some factor which interferes with the absorption of iron by the plant. Whatever the cause of the condition, the administration of soluble iron salts seems to act as a cure.

In some hilly districts in the West Highlands and the South-West of Scotland there is a condition in sheep known locally as "croitich." The chief feature is softening or fragility of the bones. The following table compares the mineral content of a pasture from an area in which this condition occurs with that of healthy hill pasture (Godden[51]):

Results calculated as Percentages of Dry Matter.

	N	CaO	P_2O_5	Na_2O	K_2O	Cl	Total Ash.	Silica-free Ash.
Healthy hill pasture	2·5	·65	·67	·37	2·66	·64	7·18	5·85
Croitich area -	2·05	·21	·29	·12	1·51	·52	5·33	2·82

The figures suggest that the disease is due to the deficiency of calcium and phosphorus.

On p. 60 reference is made to a suggestion by Haubner[26] that Molinia was a factor in causing brittle bone. Evans[52] has noted that in Wales mountain sheep and cattle whose diet consists largely of this grass are stunted in growth. The analysis shows that it is very low in both phosphorus and calcium, a sample giving 0·21% P_2O_5 and 0·36% CaO

on the dry matter. These figures are about one-third of those found in good pasture.

The small size of grazing animals in parts of Wales, the croitich in parts of Scotland, and the brittle bone on the Continent, are apparently etiologically connected, and all due to deficiency of calcium or phosphorus, or both.

In the hilly parts of the West of Scotland there is a high mortality among sheep. It was on account of this mortality that the investigation, referred to in Chapter I, begun at the instigation of Major Elliot, was undertaken. As has been stated (p. 54), there appears to be a correlation between the mineral content of the pastures and the incidence of these diseases. It is probable that deficiency of minerals in these areas is a factor not only in the conditions of malnutrition such as "croitich," but also in other diseases of obscure etiology in sheep. The subject is, however, still under investigation.

Although less work has been done in Great Britain than on the Continent on diseases in herbivora due to deficiency in minerals in the pasture or fodder, a few writers have recognised the fact that the mineral content of pastures is an important factor in determining their feeding value, and that the mineral content varies in different grazings. Thus McMillan [53] in 1875, discussing the influence of geological formation on the health and development of sheep, points out that "there are not only botanical deficiencies, but there are also richer and poorer qualities of the species of plants, one being more nutritious than another owing to the nature of the soil on which it grows," and states that "when sheep have to graze upon grass which does not contain all the earthy matters required, they will become poor in quality and predisposed to disease." Several other writers appear to have had somewhat similar ideas, though they are expressed rather vaguely.

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CHAPTER VI

DEFICIENCY DISEASES IN GRAZING ANIMALS IN AFRICA

It is known that there are wide areas in Africa where the pastures are deficient in minerals. The soil itself is deficient and the periods of drought which occur in many grazing districts accentuate the deficiency by limiting the assimilation of soil constituents by the plant. Even though native herbivora have become adapted to the pastures, in some districts they need to supplement the mineral supply of the pastures by regular visits to " salt licks." In certain areas the deficiency is so great that it leads to disease. As is to be expected, the deficiency diseases are most prominent in the parts of Africa where Europeans are developing stock farming, and introducing improved breeds which have a higher mineral requirement than the slow-growing native types.

The occurrence of these diseases has led to investigations as to their cause, and the best means of preventing them. During the last twenty years work which is of great economic importance has been done on the subject in South Africa.

South Africa.—In the Union there are large tracts of grazing lands where deficiency of phosphorus in the pasture is the direct or indirect cause of disease. " Lamsiekte " (lame sickness), " Styfsiekte " (stiff sickness) and " Pica," which have been attributed to the same cause, occur in cattle, and also, though to a less extent, in sheep and goats.

The prominent symptom of styfsiekte, and the one from which the disease derives its name, is stiffness of gait. The animals have an unthrifty appearance and become emaciated. They tend to stand with their backs arched and their hind feet well forward underneath the abdomen (Hutcheon[1]). In some cases the hoofs grow abnormally long and become turned up at the point (Theiler[2]). The bones are soft and vascular, the joints are swollen, and the articular surfaces are congested (Hutcheon[3]). The symptoms of lamsiekte are somewhat similar, but in addition there is frequently paralysis, especially of the hindquarters. Paralysis of the muscles of mastication and deglutition have been noted in some cases (Theiler[2]). Both of these conditions are associated with osteophagia (bone eating)—a form of pica.

The symptoms of these diseases have a strong resemblance to those described in the preceding chapter as occurring in Europe. Further, they are most prevalent in the same class of animals, viz.: the young growing stock and milk cows (Hutcheon[1]).

The symptoms of these cattle diseases have been described, and the probable cause discussed by many writers from the end of the eighteenth century to the present day. Le Vaillant (1785)[4] gives a graphic account of osteophagia and notes that it does not occur on good pasture. Lichtenstein (1803)[5] noted that lamsiekte did not occur in the Reit Valley near St. Helena Bay, and that cattle were sent there over "long distances for the prevention or cure of the condition." The observations made by these writers show that these diseases must have been very prevalent at that early period, and that even then it was known that the diseases were associated with definite districts, and that grazing in other districts acted as a cure.

Several theories on the causes of these conditions have been put forward by modern writers. The presence of

positive toxic substances in the pastures was suspected by Burt-Davy [6] and by Theiler [2] in his early investigations. The latter, however, showed this theory to be untenable.[7] Stead [8] suggested as the cause, deficiency of the anti-beri-beri vitamin, the lack of which in the plant he ascribed to lack of phosphorus in the soil. Theiler and his co-workers,[9] however, demonstrated by a series of feeding experiments that the disease was not due to lack of the anti-beri-beri, the antiscorbutic, or the fat-soluble vitamin.

In 1884 Hutcheon [10] put forward the theory that deficiency of phosphorus in the pasture was the cause of both lamsiekte and styfsiekte, and that " bone-chewing " was a premonitory symptom. Later, in 1892,[11] he expressed the view that when animals were debilitated by the lack of " earthy " salts, the invasion of animal parasites might become " the last straw which caused the development of loss of muscular power characteristic of lamsiekte." He noted that cattle grazing near fishing stations where they had access to fish could graze on any kind of pasture without being affected by the disease. He recommended bone meal and cereals as a preventive and stated that the former, if fed in sufficient quantities, is not only a certain preventive of lamsiekte, but also keeps the animals in good condition and increases the quantity of milk. Hutcheon's theory was supported by Juritz,[12] who in 1921 analysed plants in lamsiekte areas, and found them to be deficient in phosphorus. He concluded from this that the soils were lacking in phosphates. Woollatt [13] suggested deficiency of lime as the cause of lamsiekte and styfsiekte in Cape Colony. Borthwick [14] carried out tests and found that animals suffering from lamsiekte recovered if fed with bone meal, while controls receiving no bone meal became progressively worse. Spreull,[15] who believed the disease to be of bacterial origin, also carried out feeding tests and found that bone

meal prevented its development. He noted that animals drinking from large rivers rarely contracted the disease. Hutchinson [16] studied styfsiekte in the upper districts of Natal, where he states the soil is deficient in lime. He put forward the view that the insufficiency of lime and its salts, chiefly phosphates, is the cause of the disease in that district. He recommended the feeding of bone meal and common salt as a preventive.

Early in the beginning of the present century some farmers, following the recommendation of these writers, began to use bone meal, evidently with excellent results. Bradfield,[17] a stock farmer, reported that the feeding of bone meal had prevented the collapse of his milk cows, which had formerly been common, whereas his neighbour, who had not adopted this practice, continued to suffer loss in his herds; and Turpin [18] reported that since he had kept his animals supplied with bone meal, styfsiekte had disappeared from his farm.

The most extensive work on the cause of lamsiekte, styfsiekte and the associated pica, is that of Theiler, du Toit and Green.[19] These workers carried out a series of systematic and continuous investigations which have cleared up many points which were in dispute. Their conclusions as to the cause of these conditions to some extent confirm the views put forward by previous writers, but they now rest upon a solid basis of experimental evidence. They showed that these conditions could be prevented not only by phosphorus-rich substances, such as bone meal and bran, but also by inorganic phosphates, thus definitely pinning down the primary cause to deficiency of phosphorus. They consider lamsiekte, or at least the final symptoms of it, to be due to the *bacterium parabotulinus bovis*, which is ingested by cattle in chewing rotten bones. This is evidently the immediate cause of the paralytic

symptoms of lamsiekte. The pica for bones is due to deficiency of phosphorus. The feeding of bone meal, by supplying phosphorus, stops the pica, and thus prevents the ingestion of the bacteria, and so indirectly prevents lamsiekte.

These workers [21] also tested the effect of topdressing with super-phosphate, and found that on areas so treated, osteophagia tended to disappear, while it continued unabated on adjoining untreated areas. The application of superphosphate had evidently increased the phosphorus-content of the pastures.

In the course of the investigations of these various workers analytical data on the composition of soils and herbage have been accumulated. Juritz [20] showed that the soils on which lamsiekte occurs are extremely poor in phosphorus. The following table gives his data for lime and phosphoric acid in soils in Humansdorp :

Percentages in Soil Sifted through 3 mm. Sieve.

No.	Lime.	Available Phosphoric Acid.
1	·09	Trace
2	·54	Trace
3	·101	·005
4	·089	·008

Numbers 1 and 2 were from districts where lamsiekte was common and where there was also a heavy mortality among sheep. Juritz did not claim that the connection between the composition of the soil and the ravages of bone disease in stock had been fully established, but he states that " it is at least remarkable that these diseases find their greatest foothold in just those areas where lime and phosphates are deficient in the soil."

Theiler *et al.* [21] analysed the soil at Armoedsvlakte, where much of their work on lamsiekte was done. The

following table shows the percentage of lime and phosphoric acid found in four samples :

	I.	II.	III.	IV.
Lime	0·39	12·07	0·16	0·25
Total Phosphoric Oxide	0·02	0·12	0·03	0·03
Available Phosphoric Oxide	0·0008	0·0010	0·0005	0·0022

Both of these tables show the great poverty of the soil in phosphorus. For a fertile soil, Hall [22] gives the percentage of total phosphorus as P_2O_5 as varying from ·138 to ·258, and of available phosphorus from ·020 to ·083.

The following table shows the results of analyses by Ingle [23] of several species of pasture plants in Cape Colony.

GREEN FORAGE.

Percentages in Fresh Material.

	Tall Fescue. Festuca elatior.	*Burnet.* Poterium sanguisorba.	*Sheep's Parsley.* Petroselinum sativum.	*Prickly Pear.* Opuntia vicus indica.
Silica	1·51	0·80	0·32	0·003
Potash	1·55	0·77	1·01	0·34
Lime	0·31	0·63	0·50	0·29
Phosphorus pentoxide	0·12	0·13	0·16	0·023

HAYS.

	Oat Hay. Avena sativa. Potchefstroom.	*Blue Grass Hay.* Andropogon hirtus. Natal.	*Teff Hay.* Eragrostis abyssinica. Standerton.
Silica	2·01	3·50	3·25
Potash	—	1·04	1·28
Lime	0·18	0·47	0·30
Phosphorus pentoxide	0·34	0·28	0·24

	Maple Pea. Pisum arvense.	*Veld Hay.* Mixed grasses.	*Sweet Grass Hay.* Chloris virgata.
Silica	0·77	4·07	3·44
Potash	3·49	0·59	2·57
Lime	0·99	0·32	0·25
Phosphorus pentoxide	0·49	0·10	0·18

It will be seen that the percentages of both calcium and phosphorus in the plants are very low compared with those

of a good pasture, which are about 1 per cent. CaO and ·75 per cent. P_2O_5 (p. 10).

Taylor [24] analysed a number of species of indigenous grasses to determine the seasonal variation in the phosphorus content. His figures show a fall in the percentage of phosphorus from December to March. The fall was more marked in some plants than in others. Most of the samples contained between 0·2 and 0·4 per cent. P_2O_5.

A more extensive study of the seasonal variation in the mineral content of the pasture was made by Theiler *et al.*[21] It will be seen from the following table that there is a great difference in the percentages of phosphorus in samples taken in different months, there being a regular decrease from November to May:

Composition of Dry Matter of Grass at Armoedsvlakte.

Date of sampling.	Crude protein.	Ether extract.	Nitrogen free extractives.	Crude fibre.	Ash.	P_2O_5.	CaO.
10th Nov., 1919 -	19·4	5·5	41·0	22·5	11·6	·60	(·31)
8th Dec., 1919 -	14·3	5·6	46·8	25·6	7·7	·32	·59
15th Jan., 1920 -	13·8	5·5	48·0	25·0	7·7	·22	·50
4th March, 1920 -	7·2	3·4	49·8	33·7	5·9	·24	·43
19th April, 1920 -	4·9	2·4	51·6	35·0	6·1	·11	·46
11th May, 1920 -	4·1	2·2	52·9	34·9	5·9	·07	·50
7th June, 1920 -	4·0	2·0	53·7	33·1	7·2	·09	·59

In another series of analyses of samples, taken at weekly intervals to determine the changes in the phosphorus content, it was found that the herbage was richest in October and November, when the percentage was as high as 0·65 P_2O_5. It was poorest in June, when it reached the low level of ·04, which is the lowest percentage of phosphorus in pasture which we have found recorded in the literature. A record of the extent of osteophagia throughout the season showed that the craving for bones varied inversely with the percentage of phosphorus in the pasture, being at its highest in June, when the phosphorus content was lowest, and

falling off rapidly in October, when the phosphorus content was its highest.

As a result of all these investigations it can now be stated with a degree of certainty that the primary cause of pica, styfsiekte and lamsiekte in cattle in South Africa is deficiency of phosphorus in the pastures, and that this deficiency in the pasture is a reflection of a like deficiency in the soil.

Kenya Colony.—In this colony, where animal husbandry is being developed and imported European breeds are being introduced, malnutrition, believed to be due to deficiency of minerals in the pasture, is becoming evident. Sterility in cows is common, and in some districts mortality in calves is high (Orr [25]). In an investigation which is at present being conducted there, it has been shown that in districts where malnutrition in cattle is worst, the mineral content of the pastures is lowest. The following table shows the difference between the composition of the pastures in an area where malnutrition is very evident, and one in which the cattle thrive normally (Orr [26]):

	Naivasha. Healthy area.	*Molo.* Affected area.
CaO - - - -	1·00	·49
Na_2O - - - -	·07	·02
K_2O - - - -	2·25	·83
P_2O_5 - - - -	·93	·19
Cl - - - - -	·42	·18

A local disease occurring in the neighbourhood of Nakuru and hence called "Nakuruitis" is of special interest. Working oxen, after being in the area for from four to six months, begin to suffer from anaemia, emaciation, "running at the eyes," and in the advanced stages loss of power and co-ordination of the limbs. If the animals be removed to the Solai Plain, a few miles off, they recover in one to three months, and can be brought back to work within the area

for a further period. The condition resembles " bush-sickness " in New Zealand (p. 95). A remarkable feature of this disease is its disappearance within the last ten years from two areas, viz. : (*a*) land in the immediate vicinity of the town Nakuru, and (*b*) an area used as a remount camp during the war. In both of these areas there has been a large amount of material brought in and left in the soil. It looks as if the deficiency in the soil, which was the cause of the disease, has been made good, at least to the extent which enables oxen to graze for a year or longer without showing signs of the disease. In some recent tests which have been carried out it has been found that animals allowed to lick *ad lib.* a mixture of equal parts of common salt and ferric oxide remain healthy, while control animals on the same pasture, but without the salt lick, develop the typical symptoms of the disease. If these preliminary results be confirmed by further tests, " nakuruitis " can be regarded as the same disease as " bush-sickness," which has similar symptoms, and is also cured or prevented by the administration of iron salts (Orr [26]).

Rhodesia.—In Northern Rhodesia it is reported that the percentage of animals reaching maturity is low, and the size of full-grown animals is decreasing. The cause is attributed to in-breeding. It is significant, however, that very considerable benefits follow the feeding of bone meal, but there are no analytical results available to show whether the pasture is deficient in calcium or phosphorus. Hamilton [27] has reported that animals grazing on rough veldt in Southern Rhodesia show pica and lameness. He suggests that lack of phosphorus is the cause. Bevan [28] has called attention to high mortality in sheep in certain districts. Husband [29] states that imported pedigree cattle do not maintain their productive capacity in this colony. He suggests that this may be due to deficiency of constructive

material, *i.e.* protein and mineral matter, in the pastures. In view of the deficiency of minerals in the herbage which these observations suggest, an extensive investigation is contemplated to determine the mineral content of the pastures, and the effect of feeding mineral supplements to cattle and sheep.

Other parts of Africa.—There is little definite information about the occurrence of disease due to deficiencies in the pasture in other parts of this continent. The information which is available has been obtained mostly from replies to the questionnaire referred to on page vi. Special investigations have not been carried out in these territories, and consequently definite data do not exist. The "clinical" observations made in replies to the questionnaire, however, suggest that deficiences sufficiently marked to cause malnutrition do exist, and would be the cause of disease if improved types of cattle capable of rapid growth and heavy milk production were introduced.

Goitre occurs in young stock in the Northern Territories of the Gold Coast,[30] and is believed to be associated with deficiency of iodine. Pica, which can be prevented by feeding with bone meal, is common in the Belgian Congo (Marcq [31]), and pica for earth and salt licks is reported to occur in both East and West Africa, Somaliland, and Nyasaland and Uganda.[30] In a certain area in Uganda, a disease termed rickets is said to occur in young cattle. There are usually other signs of malnutrition, such as sterility in cows, stunted growth, and high mortality in calves, and the grading up of the stock tends to become abortive owing to retrogression to original inferior type, unless new blood of imported strain is constantly introduced. It is probable that if the necessary investigations were carried out in those districts from which pica and symptoms of malnutrition are reported,

pathological conditions affecting the bones would also be found.

Although our information with regard to deficiency diseases in grazing animals in Africa, apart from the Dominions in the South, is scanty, it is sufficient to show the existence of this veterinarian problem. The problem is likely to become more acute when the great insect-borne diseases are controlled, and the industry of animal husbandry develops on modern lines with improved breeds.

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CHAPTER VII

DEFICIENCY DISEASES IN GRAZING ANIMALS IN AUSTRALASIA

Commonwealth of Australia.—Pathological conditions which are attributed to deficiency of either phosphorus or calcium in the pasture are common in all the States of Australia, and they have received a variety of names, most of which either describe the chief symptom or indicate the district in which they occur. The conditions cause heavy losses in both cattle and sheep. Dowdy[1] refers to the appalling mortality in cattle from " dry bible " in South Australia. The animals most readily affected are milk cows during lactation or pregnancy and calves (MacKenzie,[2] Henry [3]).

In the condition known as " coastal disease " the animal becomes unthrifty in appearance, the joints become swollen and the gait gets stiff or crippled. Sometimes there are signs of paralysis, especially in the hindquarters. The bones are soft and contain a lower percentage of calcium and phosphorus than normal bones (Ramsay [4]). The condition is associated at an early stage with pica, which usually takes the form of bone-eating in cattle and wool-eating in sheep. Diseases known locally as " cripples," " stiffs," " wobbles " and " rickets " appear to be closely related to, if not identical, with coastal disease.

In the " midland disease " of Tasmania, and the " dry bible " or " impaction paralysis " of South Australia and Victoria, all the above named symptoms are present, and in addition there are those of paralysis involving specially

the muscles of mastication and deglutition. A full description of the paralytic symptoms has been given by Cameron and Gilruth.[5] The terms " dry bible " and " impaction paralysis " were used because the omasum or " bible " was found to be impacted with hard dry contents. Needham,[6] however, states that this condition is not always present, and when present is an effect, and not a cause, of the disease.

Coastal disease, with which may be included conditions evidently similar, but with different names, resembles the condition styfsiekte found in South Africa, and midland disease closely resembles lamsiekte, and has indeed been regarded by some workers as the same disease (Bruce,[7] Henry,[3] Needham [6]). It seems probable that the conditions in their initial forms are essentially the same, but in midland disease there may be additional symptoms of paralysis due to micro-organisms, which Seddon [8] has suggested may be ingested through the eating of rotten carcases by animals suffering from pica. As the present interest in these diseases is limited to their connection with deficiencies in the pastures, and as it has been shown that this is a primary factor in all cases, it will be convenient to deal with them here as one group, recognising of course that factors other than deficiencies of minerals in the pasture may be involved in some of the symptoms.

The Report of the Minister of Agriculture for South Australia [9] states that coastal disease occurs where there is a lack of lime and iron, and that it is associated with bone chewing. Crushed bone with " licks," including iron licks, and the placing of lime in the drinking troughs are recommended. Needham [10] attributed midland disease to the lack of phosphates in the soil. According to this writer, Valentine,[11] whose original paper we have been unable to trace, was the first to advance the theory of deficiency of phosphates as the cause of this condition and to recommend

the feeding of bone meal or other foodstuffs rich in phosphorus in the districts where "impaction paralysis" occurred. Pentland,[12, 13] in Victoria, showed that pica and paralysis could be prevented by giving bone meal and salt with phosphate of lime and sulphate of iron, or by dressing the land with superphosphates, and that pica disappeared on land which had been manured with bone dust. In 1902 Dowdy [1] showed that similar measures were a preventive for dry bible in South Australia.

These conclusions have been confirmed by later workers, who have shown that pica, which may be regarded as a premonitory symptom of all these pathological conditions, occurs on geological formations with soils poor in lime and phosphorus or both (Jensen [4]). They have shown also that the provision of salt licks consisting of phosphate of lime, or the removal of animals to districts with rich soils, is a certain method of prevention. Henry [14] has summarised the position in a recent paper, in which he shows that the measures adopted to prevent pica and osteomalacia and similar conditions affecting the skeleton, have also a preventive influence on worm infection and on sterility, abortion, and debility of animals at birth, some forms of which breeding troubles are now known to be due to deficiency of minerals in the food (Mendel,[15] Meigs,[16] Davidson [17]). The acute paralytic symptoms of midland disease attributed to botulism are also indirectly prevented, since the stopping of the pica puts an end to the ingestion of putrefying bones containing the bacillus para-botulinus (Seddon [8]).

Increase of the diseases during drought has been noted by most of the observers, *e.g.* Henry,[3] Dowdy,[1] Kendall.[18] These workers have recognised the fact, brought out in Chapter III, that drought affects the mineral content of pastures.

The influence of deep-rooting plants in affording

protection against these diseases has been noted by Colbourn [19] and Murphy.[20] The explanation given is that the deep-rooting plants can draw supplies of calcium and phosphorus from the sub-soil, which has not been depleted to the same extent as the surface layers, and that they also suffer less from drought, which of course affects first the plants with shallow roots. Owing to the depletion of pastures, the incidence of these diseases, due to lack of calcium and phosphorus, is increasing, and they are appearing in new areas. The extent of this depletion has recently been emphasised by Richardson.[21]

An interesting note on natural salt licks has been made by Jones,[22] who observed that sheep at Burrowa, New South Wales, ate earth on certain spots, and that when weak or "wormy" sheep were given earth from these lickholes they improved rapidly. He states that the paddock in which these natural salt licks were found was the only sound paddock in the district. Sheep on it had a very low mortality rate. He analysed the material and found it to be rich in iron. In addition to 80·40 per cent. of silica and 3·8 per cent. of moisture, it contained in percentages: Fe_2O_3, 7·10; P_2O_5, 0·37; CaO, 0·63; Cl (equivalent to sodium chloride), 0·87.

The results of soil analyses have shown a close correlation between poverty of the soil in phosphorus and calcium and the incidence of these diseases. Howell [23] gives the following figures for soils from two paddocks in Winton in Victoria, where mortality was heavy, and for comparison the average analyses of good soils:

	Percentages of:			
	P_2O_5	K_2O	CaO	Cl
No. 1 paddock -	·032	·192	·240	·003
No. 2 paddock -	·037	·290	·214	?
Good soils - -	·150	·200	·400 (up to)	·035

Cherry [24] analysed soils in different districts of Victoria, and found that they were all poor in phosphorus: the poverty being most marked in the Mallee soils, in some samples of which the percentage was as low as ·005. Paterson and Scott [25] also analysed Victorian soils for their phosphorus content and found them, compared with European soils, to be poor, especially in available phosphorus. In the following table the figures, which in the original are given in parts per 100,000, are reduced to percentages to bring them into line with the other data given here.

P_2O_5 PER 100 GRS. DRY SOIL.

	Available.	Total.
Wimmera - - - -	·0078	·052
Mallee - - - - -	·0045	·050
Coultoun Valley - - -	·0036	·068
English Soil (Hall) - -	·0192	·092

Jensen,[26] who was interested in the correlation between geological formation and incidence of these deficiency diseases, compared the lime, potash and phosphorus content of affected and non-affected areas on granite soils in New South Wales.

	CaO	K_2O	P_2O_5
Area affected with bone chewing	·146	·069	·053
Non-affected area - - -	·529	·253	·115

Further analyses of soil in New South Wales by Jensen [4] yielded similar results, *e.g.*:

	CaO	K_2O	P_2O_5
Av. of 17 soils from affected area	·168	·087	·047
Av. non-affected area - -	·465	·143	·184

Henry [3] quotes the analyses of a number of soils in the Bega district of New South Wales where, following a drought in 1912, there was a heavy mortality from osteomalacia. The results show that the disease occurred on soils deficient in lime, potash and phosphorus.

		CaO	K_2O	P_2O_5	
(1)	-	·616	·417	·152	No disease.
(2)	-	·566	·341	·157	,, ,,
(3)	-	·340	·314	·140	,, ,,
(4)	-	·271	·112	·109	Very little sickness.
(5)	-	·225	·023	·070	Mortality heavy.
(6)	-	·118	·101	·070	,, ,,

The results of these recorded soil analyses in affected and non-affected areas, show low percentages of lime, potash and phosphorus in the former as compared with the latter. Compared with ordinary fertile soils, the deficiency of phosphorus is, on the whole, more marked than deficiency of lime. This is in accordance with the prevailing view that there is a marked phosphorus deficiency generally in Australia, and that lack of phosphorus in the soil is the chief root evil of these deficiency diseases in stock.

In the data given by Jensen and Henry for New South Wales soils the difference between the percentage of potash in affected and non-affected areas is as great as in the case of lime or phosphorus. In Howell's data for affected soils in Winton, however, the percentage of potash is not low. There is no reason to believe that deficiency of potash in the plant is a cause of disease. It is probable, however, that deficiency of potash in the soil may limit the rate of growth of the plants, and so indirectly affect the calcium and phosphorus content of the pastures. In addition the amount of potash affects the bulk of the pasture and hence has an influence on the general health of the animals.

These soil deficiencies are reflected in the pastures. Kincaid [27] investigated the phosphorus content of native Australian and acclimatised European grasses. She found that Australian native grasses have a lower phosphorus content than the same kind of grass grown in Europe. In

twelve different samples the average of P_2O_5 ranged from 0·098 in Panicum effusum (hairy millet grass) to 0·2994 in Arundo phragmites (reed grass). These figures are very low compared with British grasses (p. 34).

Underwood,[28] working with Paterson in Western Australia, has recently analysed a number of samples of pasture. The phosphorus content of all samples was low. In six samples from what are termed " good quality " the percentage as P_2O_5 on the dry matter varied from 0·269 to 0·550, and in six samples of poor quality pasture from 0·154 to 0·276. The low phosphorus content was correlated with a low protein content. The average of the total silica-free ash in poor pastures was 3·6 compared with 7·03 in good pastures. No difference, however, was found in caloric value.

Ramsay[4] and Henry[3] compared the mineral content of pastures in areas affected with deficiency diseases with that in non-affected areas. The former calculated the daily intake on the assumption that the cows eat 56 lbs. of grass per day.

Average Daily Intake by Cows in Oz.

P_2O_5	CaO	MgO	K_2O	
·78	·99	·45	3·02	Affected area.
·72	·99	·46	2·33	
·88	1·26	·50	2·75	
·90	1·30	·51	3·13	
1·66	1·21	·62	4·42	Non-affected area.
1·67	1·25	·56	4·56	

It is seen that the most marked difference between the affected and non-affected area is in the amounts of phosphorus supplied by the pasture.

Henry gives the following figures. In the table numbers 1 and 2 are from non-affected areas. Numbers 3-6 are from areas with a heavy mortality.

Percentages in Dry Matter of Pasture:

	CaO	MgO	K_2O	P_2O_5	
(1)	·42	·19	1·53	·56	Non-affected area.
(2)	·41	·21	1·48	·56	
(3)	·44	·17	1·05	·30	Affected area.
(4)	·42	·17	·93	·30	
(5)	·34	·15	·72	·24	
(6)	·33	·15	1·02	·27	

According to the analytical data quoted here, all the minerals tend to be lower in the pasture in the affected areas. There is, however, no reason to think that the amount of either magnesium or potassium present would be insufficient for the requirement of the animal. With regard to calcium and phosphorus, there is more difference between the percentage of phosphorus in the two areas than that of calcium. The data from the analyses of pasture is therefore, in accordance with those of soils, in indicating deficiency of phosphorus as being the origin of the disease in the affected areas.

One other set of analyses may be quoted as being of special interest. "Salt bushes" are known to have a marked beneficial effect on the health of stock. Murphy [20] refers to this when discussing the predilection of cattle for food rich in minerals essential for the health of the animals. The following tables from Audas [29] show that these salt bushes are very rich in both phosphorus and calcium.

Analysis of:

	Kochia pyramidata and "Grey Bush."	Atriplex mummularia "Old Man Salt-Bush."
	Percentage on plant.	Percentage on plant.
K_2O	4·62	4·91
Na_2O	12·83	9·25
NaCl	9·93	9·47
CaO	3·26	2·71
MgO	2·72	2·12
P_2O_5	1·48	1·28

Brunnich [30] analysed both individual species of grasses and fodder plants, and mixed samples of pasture, from

different districts in Queensland. His results showed that the percentages of the mineral nutrients varied with different districts. The percentage of phosphorus as P_2O_5 varied from 0·31% to 0·64%, and that of calcium as CaO from 0·29% to 0·7%.

These figures show that while in Queensland there are deficient areas, there are also areas in which the mineral content of the pasture is fairly high. This is further brought out by Brunnich's [31] analysis of a large number of soils from various parts of Queensland. In these the total P_2O_5 ranges from 0·02 to 0·4, and the CaO from 0·08 to 4·4.

These variations in mineral content of the soils and pastures furnish the explanation for the fact that in some areas the use of phosphates produces no beneficial effect, while in others it results in spectacular improvements in crop production, and in the stock-carrying capacity of the land.

The above brief review does not pretend to give a complete account of all the valuable work which has been done on these diseases or on pasture or soil problems in Australia. It has been necessary to limit the references to those parts of the work which have a direct bearing on the special aspect of the subject under discussion. A complete systematic account of all the work which has been done in this continent, on soils and pastures and on diseases originating in deficiencies *of any kind* in the pasture, would be not only a valuable contribution to scientific literature, but of great assistance as a guide to the various workers engaged on those researches in pasture which are likely to yield information which will accelerate the development of animal husbandry in Australia.

The present account, however, inadequate though it be, is sufficient to show that the composition of the soil, the composition of the pasture and the health of the grazing

animal are intimately connected. In this respect the work in Australia has run parallel, and to a large extent concurrently, with the work in South Africa, and has quite independently reached the same general conclusions as the earlier European workers, who were concerned chiefly with hay fed in winter rather than pasture directly grazed.

New Zealand.—In New Zealand the following diseases have been attributed to deficiency of minerals in the pastures: "bush-sickness" in sheep and cattle, "Waihi disease" in milk cows, "osteomalacia" or "osseous cachexia" in cattle and sheep, and "osteoporosis" in horses.

Bush sickness has been recognised for the last thirty or forty years by settlers, who have occasionally given it the descriptive term of the "skinnies." The chief symptoms, progressive anaemia and emaciation, appear usually within about five or six months after the stock enter the badly affected area. Sheep show symptoms earlier than cattle. Post-mortem examinations reveal little that is abnormal, except extreme anaemia.

The disease is confined to the areas of country in the North Island, embracing the counties of Rotorua, Matamata and Tauranga. The soil on which it occurs consists of coarse pumice particles, derived from showers of material ejected from volcanoes. It is estimated that about a million acres of land are involved.

The occurrence of the disease was noted by Park [1, 2] and Gilruth [3] who described the symptoms. Investigations on the etiology have been carried out by Aston and Reakes,[4—28] and recently by Grimmett in association with Aston.[29] It has been shown that the herbage in the affected area contains less iron than that of healthy districts (see table p. 99). The total ash, including iron, in the pasture

is lower in spring and summer than later in the year. It is in these seasons when the percentage of iron is lowest that animals suffer most from bush sickness.

As a result of these investigations the hypothesis has been put forward that the disease is a primary anaemia due to iron starvation. It is suggested that the reason why sheep are more susceptible than cattle, and that horses are unaffected, is to be found in their different rates of growth and therefore their different requirements for iron. The sheep doubles its weight in fifteen days, while a calf takes four or five times that period, and a foal still longer. Support for this suggestion is found in the percentage of iron in the milk of the species, viz. 0·00079 per cent. in the sheep, 0·00014 per cent. in the cow and 0·00007 per cent. in the mare. The administration of certain soluble iron salts, *e.g.* ferric ammonium citrate, both cures and prevents the onset of the disease.

There does not appear to be an absolute deficiency of iron in the soil, but the iron present is almost entirely in the form of silicate of iron, which is extremely insoluble and unavailable for the plants. The excess of manganese in the soil is suggested as a factor limiting the assimilation of iron. In addition to being deficient in iron, the pastures are also deficient in phosphorus. The application of phosphates to the soil prolongs the period during which the animal may remain in health, but it does not prevent the occurrence of the disease.

This New Zealand work is of special interest in so far as it is the only recorded instance in the literature in which deficiency of iron in pastures has been demonstrated to be the cause of progressive anaemia in herbivora. It is probable that the condition is similar to " Nakuruitis," which occurs in a limited area in Kenya (p. 82), to " pining," which occurs in Scotland (p. 70), and to a disease recently

described by Dickinson [30] as occurring in cattle in King Island, Tasmania.

Reid and Aston [31, 32] describe a disease which they term "osseous cachexia" which occurs in sheep and cattle. It was especially prevalent in sheep in certain areas. The disease "is characterised by disturbance of nutrition, leading to resorption of calcareous salts from the bones, which in consequence become soft and fragile." Data on analyses of bones of affected animals and of soils on which the condition occurs, are given. It is concluded from these that the cause is an excess of organic matter and deficiency of lime salts in the soil. These writers refer to the influence of the character of the soil on the nutritive value of flora, and also on effect of droughts which lead "to the growth of feeds having dearth of nutritive elements, especially of salts."

Reakes [33] and Reid [34] described a form of malnutrition termed "Waihi disease," because the cases first described occurred near a small village named Waihi in North Taranaki. The animals have a stilted gait which simulates cramp or rheumatism, the fore-legs being specially affected. The hoofs grow abnormally long, nodular enlargements appear on the ribs, which on post-mortem examination are found to be soft and spongy. The animals become weak and emaciated.

The disease is prevalent on light soils, "the herbage of which has been depleted of its nutritional value by continued grazing without cultivation or manuring." The application of basic slag to the soil "has proved most valuable in diminishing the incidence of this complaint." No data on analysis of the pasture are available. The description of the disease, however, and the fact that it is prevented by the administration of bone meal or Parrish's Chemical Food (syrup of phosphate of iron), or top-dressing

with superphosphates, suggest that it is due to a deficiency of phosphorus.

It is interesting to note that the fact that top-dressing with superphosphate prevented this disease, helped to popularise the practice of top-dressing. Though top-dressing had been commenced experimentally by the Department of Agriculture in 1908, it was still in the early stage of development, and the realisation of its value in preventing "Waihi" disease caused the practice to be extended, especially in the areas where the trouble had manifested itself (Reakes [35]).

Reakes [33] also describes under the term "osteomalacia" or "osseous cachexia" a somewhat similar condition in sheep. The bones become fragile and the animals emaciated. On healthy farms, the available phosphorus in the soil has been found to be six times as great as on affected farms. Reakes suggests that the disease is due to lack of phosphate of lime in the herbage as a result of a deficiency of phosphorus in the soil. A somewhat similar condition occurs in sheep in the Marlborough and Wellington Provinces which Reakes attributed to deficiency of lime salts.

Aston and Wright [36] have recently investigated a malnutrition disease in sheep in the central district of the North Island. The carrying capacity of the pastures has decreased, and even with diminished stocking, animals do not thrive. Preliminary examination of soil and pasture has shown that both are deficient in calcium. Post-mortem examination shows fragility of the bones. Analysis of soil and pastures has shown a deficiency of calcium as compared with adjoining calcium-rich land, but sufficient work has not yet been done to allow definite conclusions to be drawn.

In connection with these investigations on deficiency diseases, a number of analyses of soils and pasture have been done chiefly by Aston [22] in his studies on the etiology of

bush sickness. The following table, taken from his data, compares the composition of a pumice soil on (*a*) a bush-sick area and (*b*) a non-bush-sick area with a non-pumice soil in the same part of the country:

1 PER CENT. CITRIC ACID EXTRACT (DYER'S METHOD).

		Percentage of:		
		CaO	P_2O_5	Fe
Pumice Soil	Bush-sick - -	0·131	0·006	0·067
	Healthy - -	0·158	0·011	0·102
Non-pumice Soil	Healthy - -	0·186	0·044	0·135
	Healthy - -	0·192	0·047	0·240

The available phosphorus is low, and it has been found that the application of phosphorus to the soil leads to improvement in the nutrition of the grazing animal, though, as has been noted above, it does not prevent the ultimate development of bush sickness (Reakes and Aston [19]).

In connection with the composition of the pastures, the chief interest has been in the iron content. The following figures (Aston [23]) show the difference between the percentage of iron in clover grown on a bush-sick soil and that grown on healthy soil:

ANALYSES OF CLOVERS.

FROM BUSH-SICK COUNTRY.			FROM HEALTHY COUNTRY.		
Month Collected.	Species.	% Fe in Ash.	Month Collected.	Species.	% Fe in Ash.
January	White Clover	0·137	January	White Clover	0·405
March	,, ,,	0·220	January	Red ,,	1·940
March	Red ,,	0·141	March	White ,,	0·672
March	White ,,	0·150	March	,, ,,	1·240

Work on the mineral content of pastures is being carried out at the Cawthron Institute in the South Island. The results, which have not yet been published, show that there are several areas in the Nelson district where serious loss of stock occurs, and deficiency diseases are suspected to be the cause. In the Moutere Hills analysis have shown that

the pastures in these areas are poorer in certain constituents than those of healthy districts. Field tests are in progress in which the effect of (*a*) top-dressing, (*b*) supplying a salt lick, is being investigated. Preliminary reports indicate positive results in both cases.

The results of the investigations referred to above show that in New Zealand there are areas where the pastures are so deficient in some mineral elements that deficiency diseases occur. A systematic investigation of the whole subject is at present being carried out under the direction of the competent workers referred to above, who have already thrown much light on the subject. Within a few years the increased number of workers on this important aspect of pasture husbandry will have obtained information which will be of scientific interest and may be of considerable economic importance to the Dominion.

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CHAPTER VIII.

DEFICIENCY DISEASES IN GRAZING ANIMALS IN AMERICA.

United States.—Two pathological conditions " creeps," and " loin disease," which seem to be closely allied, occur in certain parts of Texas. Parker,[1] who described " creeps," which appears especially in winter and early spring, considered that it was identical with osteomalacia. The disease has been recently studied by Schmidt.[2, 3] He states that it is specially prevalent in dry years, and that it is cured by bone meal. This fact suggests that deficiency of phosphorus or calcium is the cause of the disease.

Schmidt[3] has described a disease occurring in cattle in Texas and referred to as " loin disease." It is localised in certain areas, the chief symptoms being pica, stiffness of gait and inco-ordination of movement. Schmidt suggests a deficiency in the herbage as the cause, and recommends the feeding of bone meal. It is very probable that this condition is closely allied to the disease known as " creeps."

Cary[4] describes a condition known as " sweeny " or " creeping sickness " which occurs in the wire grass region in the southern part of Alabama, where he states the land is sandy and poor in lime. He considers the cause of the disease to be deficiency of lime, phosphorus and fat soluble A.

At Wisconsin interesting results have been obtained on the effect of calcium deficiency on reproduction in cattle.

Though the work did not arise from observations of pathological conditions occurring on farms, it has a direct bearing upon the mineral content of pastures, and should be referred to here. Hart and co-workers [5, 6] showed that abortion or birth of weak calves occurred when cows were fed on forage which was poor in calcium. The addition of a calcium salt, or of certain calcium-rich substances, to the calcium-deficient ration, was followed by birth of healthy calves.

These workers [7] call attention to the important relationship of the soil to the plant, and state that corn stover grown in acid soils in Wisconsin has as low a lime content as 0·31%. The same is true of blue grass or timothy hay.

Hart, Beach, Delwiche and Bailey [8] have recently investigated a "mysterious disease" which occurs among some of the dairy herds of Door County in Wisconsin. The typical symptoms are pica, stiffness of the limbs, swollen joints and emaciation. The limbs and ribs are easily broken. Cows with a long milking history are the ones most affected. The writers state that the deficiency causing the disease seems to be phosphorus. Analyses of clover and alfalfa from the affected area show that the percentage of phosphorus as P_2O_5 is low. In four samples it varied between 0·200 and 0·328.

The work of Huffman and Taylor [9] shows that similar troubles occur in Northern Michigan. The result of investigations point to phosphorus as the deficient mineral. These workers state that the feeding of bone meal prevents the onset of symptoms.

In Minnesota, according to Eckles,[10] there is an area of eight thousand square miles in the region of the valley of the Red River, where the problem of mineral deficiency is acute. The growth of young cattle is sub-normal, and cows decline in milk more rapidly than normal. Eckles,

Becker and Palmer [10] state that in certain farms in this state the cattle are stunted in growth, the heads being too large for the bodies, and the fertility of cows is low.

The analyses of some samples of hay from the district are given below:

Mineral Composition of Hay from Affected Areas.

	Percentages of:	
	CaO	P_2O_5
Alfalfa Hay:		
Affected - - - -	2·646	0·434
Prairie Hay:		
Affected - - - -	0·578	0·229
Timothy Hay:		
Affected - - - -	0·550	0·245

Analysis of samples from districts stated to be non-affected were only slightly higher than the above. There is obviously a deficiency of phosphorus in the whole district. Indeed, deficiency of phosphorus was definitely proved to be the cause by Eckles and his co-workers, who prevented the symptoms of deficiency by feeding sodium phosphate. It is suggested by them that the non-appearance of the trouble in non-affected areas is due to "better feeding practices."

These workers consider that lack of ovulation in cows on the affected farms is most probably due to mineral deficiency. Increase in fertility has been found to follow the use of bone meal, and the soil of the region where these troubles appear responds in a striking manner to the application of phosphatic manures. Eckles and his co-workers consider that their results show an important relationship between mineral deficiency and reproduction.

In the state of Montana, Welch [11] states that there is a large area deficient in lime and phosphorus. Animals suffer from pica, stiffness and lameness, softening of the bones and emaciation. It is only on a few ranches, however, that the deficiency is so acute as to cause death of the cattle.

In the Hawaiian Islands, where the soil is of volcanic origin and is poor in lime, cattle have a slow rate of growth and the milk yield of cows is low. It is stated that the feeding of bone meal or other lime-rich foods improves the condition of the animals. No figures are available, however, to show the composition of the pastures (Mohler [12]).

There appear to be some areas in the northern parts of the United States where the vegetation is deficient in iodine. Ennis Smith [13] attributes pathological conditions in breeding sows to this cause. He claims that the vegetation in affected areas contains less iodine than in unaffected areas.

Goitre—a condition associated with deficiency of iodine —was at one time prevalent in sheep in Michigan. It is of widespread occurrence in human beings, and it is probable that this is correlated with its occurrence in animals. The use of salt found in deposits round the Great Lakes led to a rapid decrease in the incidence of the disease. Marine [14] considers that the beneficial effect of the salt was due chiefly to the iodine present in it. McClendon and Hathaway [15] have found that the iodine content of the food and drinking water is lower in the goitre than in the non-goitre areas.

The results of the recent American work referred to above show that there are areas in the United States where the mineral deficiency in the pasture is so extreme as to cause gross malnutrition in grazing animals. The investigations now being undertaken at several of the experiment stations will greatly increase our knowledge of the subject within the next few years.

Canada.—The natural pastures of Canada appear to be comparatively free from marked deficiencies. It is recognised that as a result of depletion there is a deficiency of lime in the soil of the Maritime Provinces and that the amount of phosphorus is below the optimum. This state-

ment is supported by soil analysis and fertiliser experiments conducted over a period of years by Dr. F. T. Shutt, Dominion Chemist.

On the whole, the cattle throughout the four Eastern provinces in most districts lack the size which might be expected considering the breeds and the foundation stock from which they came. The data, however, are inadequate to determine whether this is due to deficiency of minerals in the pastures and stored winter forage crops, or to insufficient attention to proper nutritional practices (Archibald [16]).

We have been unable to find any analysis of pastures, but the result of soil analysis shows deficiency of lime in Quebec province (Nagant [17] ; McKibbin [18] ; McTaggart [19]). It is unfortunate that as yet there is not sufficient information available to give conclusive proof that this shortage in the soil materially affects the composition of the forage. Results of the work on soils, however, together with "clinical" observations on the cattle, strongly suggest that there may be a shortage of calcium and probably also of phosphorus in the pasture. It is possible, as has occurred in other parts of the world (p. 53), that a process of depletion has been going on. In no district, however, is the deficiency in the pasture sufficiently marked to produce such gross signs of disease as have been noted in South Africa, Australia, and New Zealand. The mineral content of pastures has, therefore, not received as much attention in Canada as in those countries where diseases in grazing animals due to deficiency of minerals are common.

Canada's chief contribution to our knowledge of this subject has been in connection with iodine. In almost all parts of Canada, goitre in lambs, and also though to a less extent in cattle and goats, appears periodically. In some years it is noted in districts all over the Dominion. In other years it is almost completely absent. Simple goitre is now

believed by many workers (Orr and Leitch [20]) to be due to lack of sufficient iodine in the food.* It has not been definitely established, however, whether in this case the deficiency is in the pasture or in the food used during the winter months. All over the world simple goitre is a disease generally localised in fairly well-defined areas. If it be associated with deficiency of iodine, as is most commonly believed, the deficiency is most probably in the pasture. This view is supported by the observation of Standish,[21] who noted that in Nova Scotia locality has a predisposing effect, animals grazing on soils rich in lime and magnesium being prone to the disease. It is known that in limestone areas the iodine content of the soil is apt to be low, an excess of calcium facilitating the leaching of iodine out of the soil (Hercus, Benson and Carter [22]).

The effects of the administration of potassium iodide to grazing animals have been tested for several years by the Animal Husbandry Division (Archibald [16]). The administration of this salt has been found to prevent goitre in lambs and calves (Helmer [23]), (Tinline [24]), Torrance [25]). Morrison [26] also reports similar results through the administration of potassium iodide to pregnant dams. Barton [27] states that the administration of iodine has eliminated goitre from the flock belonging to McDonald College. These findings are in accordance with the results obtained in human beings in Switzerland in recent years (Silberschmidt [28]).

Rothwell's [29] investigations on the effect of potassium iodide on joint-ill in foals is an important aspect of this Canadian work on iodine deficiency. He has found that the administration of potassium iodide to mares prevents

* It should be noted that there are forms of goitre, notably exophthalmic goitre, due to causes other than lack of iodine. These, however, occur more commonly in human beings than in farm animals.

the appearance of joint-ill in foals. The writer has been informed by Mr. O'Brien of the Glasgow College of Agriculture that Rothwell's research has been applied successfully on a stud in the South-West of Scotland, the administration of potassium iodide to mares being followed by the disappearance of joint-ill in the foals.

A review of the Canadian literature seems to show that, apart from the problem of iodine deficiency, which for practical purposes can be considered as solved, the question of deficiency of minerals in the pasture is not one of practical importance so far as concerns the prevention of deficiency diseases. It is likely, however, to become of increasing importance with the development of the work for the improvement of pastures for increased production which is being done on the depleted areas of the Eastern Province.

Central and South America.—There is little information with regard to the composition of pastures in South America. In the British Honduras pica has been noted, and sterility is high and the milk yield is low.[30] There are no data to show whether or to what extent these conditions are due to deficiencies in the pasture.

In British Guiana there is stated to be a deficiency of bone-forming elements in some of the grasses of the coast land, and soils in the interior of the colony are poor in both lime and phosphorus. The lack of these elements is believed to be the cause of the heavy death rate which occurs among sheep, and the low milk yield in cows.[30]

In the Falkland Islands, there has in recent years been a steady decrease in the size of animals from one generation to another. Among sheep mortality in lambs is increasing, due to weakness of the lambs at birth (Munro [31]). Pica is prevalent. Analyses of both soils and pastures have shown that the most marked deficiency in this case is calcium (Godden [32]).

In the Leeward Islands the herbage is said to be deficient in mineral salts, the deficiency being of the same nature as that of the Falkland Islands.[30]

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CHAPTER IX

DEFICIENCY DISEASES IN GRAZING ANIMALS IN ASIA

India.—Cattle in India in general are of poor quality and malnutrition is common. It is difficult, however, to estimate to what extent the malnutrition is due to lack of any particular food constituent, as the conditions appear to be such that the effects of any particular deficiency tend to be overshadowed by the effects of sheer starvation. Undernutrition, owing to lack of sufficient pasture for the number of animals in the country, appears to be the chief problem in animal nutrition in India. In addition to general undernutrition, however, there are evidently in certain areas marked deficiencies of minerals in the herbage. It is known that in many districts, and probably generally all over this sub-continent, the soil is poor in phosphates. Thus in Bihar soils, Davis [1] found that the total phosphorus percentage varied between ·086 and ·137, and the available, from a trace to ·002 compared with about ·27 and ·16 respectively in good soils. The Report of the Department of Agriculture of Madras for 1918-19 states that the crying need for almost all crops in Southern India is phosphoric acid. We have no data showing how far this deficiency in the soil is reflected in the pastures. It seems certain, however, that analyses of the pasture would show deficiencies of phosphorus and probably also of other minerals. It has indeed been shown by Davis [1] that lack of phosphorus

in the soil is correlated with a low phosphorus content of rice grown on it.

The lack of phosphorus in the soil in India is, to some extent at least, the result of depletion. There has been a long continued export of phosphorus in the form of bones, without any compensatory return. In the five years, 1920-25, over 520,000 tons were exported, while in the same period the import of chemical fertilisers amounted to only about 5,000 tons.

This poverty of the soil in phosphorus affects not only the composition but also the bulk of the pasture. Richardson [2] in Australia has shown that the enrichment of soils poor in phosphorus by application of phosphatic manures can increase the yield of hay by nearly 100 per cent. Deficiency of phosphorus in the soil is therefore probably an important factor both in under-nutrition and in malnutrition.

Davis [3] attributes low milk yield of cows in Bihar to deficiency in phosphorus in the pastures, and McCarrison [4] has stated that in Bihar and on the coast of Malabar mortality among cattle is high, sterility is common, and the milk yield of cows is low. These conditions are associated with pica. McCarrison suspects the cause to be lack of phosphorus.

It is probable that cattle in India suffer from deficiency of minerals other than phosphorus. Warth [5] put forward the idea that there may be a deficiency of common salt, *i.e.* of sodium or chlorine. It is a well-known fact that lack of salt has an adverse effect on the health and productivity of cattle, and that the requirements for salt are specially high in hot climates (p. 126).

The extensive investigations of McCarrison [4] have indicated that there is a shortage of iodine in areas in the region of the Himalayas, but so far as is known this shortage

is not associated with high incidence of goitre and its sequelae in cattle, though these conditions are very prevalent in human beings in some of the Himalayan regions (McCarrison [6]).

The economic importance of deficiency of minerals in the pasture was referred to by several witnesses giving evidence before the recent Commission on Agriculture in India. Mr. Smith, the dairy expert, said that in many parts of the country the local fodders were deficient in mineral matter. Mr. Warth, chemist, Bangalore, offered the opinion that it was impossible to lay too much stress on this subject. He believed shortages of calcium, phosphorus, sodium and chlorine occurred in various parts of the Empire, and that deficiency of phosphorus was perhaps the most important Indian problem. McCarrison, who has done exceedingly valuable work on deficiency diseases, also emphasised the importance of deficiency of minerals, especially of phosphorus and iodine, in causing malnutrition, which he regarded as the most far-reaching cause of disease in India.

So far as can be gathered from the literature there has been no systematic work in India to determine whether feeding of mineral mixtures or mineral-rich substances to make good the deficiencies in the pastures and fodders would have any effect in preventing malnutrition in cattle. The only evidence we have been able to obtain is in a private communication from Lt.-Col. Matson, who states that in the crossing of certain European breeds with Indian cattle, the second cross display " a number of defects of health," and some of these defects are " assuaged by a mixed mineral diet, *i.e.* those cross-bred cattle have recovered health and condition when consuming a larger amount of mineral matter than native Indian cattle could be induced to eat." It is interesting to note that the

improved breeds with their greater capacity for growth and production had a greater appetite for the mineral mixture than the native cattle.

It is obvious that India represents an interesting field of investigation on this subject. Officials responsible for the direction of agricultural research are fully aware of the nature and of the importance of the problem, and if the necessary funds and facilities are provided there is a likelihood of work of great economic importance for India being carried out within the next few years.

There is no reliable information with regard to other countries in Asia with the exception of the Island of Cyprus. In this island pica is fairly common in cattle, sheep and goats, imported breeds being more susceptible than native breeds. Stiffness and lameness occur in oxen, and in some areas as many as 20 per cent. are affected. In long-standing cases deformity of the hoof occurs. The condition is believed to be due to lack of lime or phosphorus.[7]

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CHAPTER X

DEFICIENCY DISEASES IN HORSES

THE rate of growth in the horse is slower than in cattle or sheep. The foal takes 60 days after birth to double its weight, compared with 47 in the calf and 15 in the lamb. Further, the horse has not been bred for rapid growth to the same extent as beef cattle have, nor has it been bred for milk production. The mineral requirements of the horse are therefore relatively not so great as those of cattle and sheep. Hence pathological conditions due to deficiency of minerals are not so common in horses as in ruminants. The size and quality of horses in different districts have, however, been associated with the mineral content of the pastures in these districts, and certain diseases have been attributed to deficiency of calcium or phosphorus, or to an abnormal ratio of these in pastures or hay.

Osteoporosis.—The most important disease which has been attributed to deficiency of minerals is osteoporosis. Descriptions of this condition are given by several workers, *e.g.* Mohler,[1] Friedberger and Fröhner.[2] The chief characteristic of the disease is progressive decalcification of the skeleton, resulting in enlarged, soft or porous bones. This condition is especially manifest in the bones of the head, causing enlargement and bulging of the face. On account of this peculiarity the disease has been termed "big head" or "swollen face." The percentage of calcium and phosphorus in the bones is lower than that of healthy bones (Ingle [3]).

Accompanying these bony changes there is stiffness and lameness and also general signs of malnutrition, *e.g.* rough coat, emaciation and lassitude.

The disease has been described as occurring in many parts of the world, viz.: South Africa (Hutcheon [4] and others), India (Place [5]), Ceylon (Sturgess [6]), Madagascar (Charon and Thiroux [7]), the East Indies (Muller [8]), and parts of the United States, the Hawaiian Islands and the Philippines (Mohler [1]), the Sandwich Islands (Loxton [9]), the Fiji Islands (Turbet [10]). It has been noticed as occurring, though rarely, in Australia and New Zealand (Reid [11]). It is not common in Europe, though a somewhat similar condition, "Krusch" disease, or "bran sickness," occurs in horses fed too exclusively on bran (Mohler,[1] Friedberger and Fröhner [2]).

A number of writers have associated osteoporosis in horses with lack of calcium or phosphorus in the pastures or in the forage. Germain,[12] who studied the disease in horses imported from Egypt to Cochin China, ascribed the cause to lack of calcium in the Cochin China hay, the ash of which, according to him, contained only 2·97 per cent. of lime, compared with 18·24 per cent. in European samples.

Hutyra and Marek [13] state that in some districts in Western Flanders, where colts are affected during the grazing season, the cause has been ascribed by veterinarians to lack of lime in the soil, but no figures are given to show the percentage of calcium in the pastures in these districts. French veterinarians who have studied the condition in Madagascar ascribe it to deficiency of lime or phosphorus (Charon and Thiroux [7]). A good deal of research on the disease has been done in South Africa. Hutcheon [14] noted that the progress of the disease could be arrested by moving the horses to the Karroo. Cattle on the Karroo rarely develop lamsiekte or styfsiekte, which are both due to

deficiency of minerals in the pastures (p. 81). He also noted that some horses fed on a ration of mealies, oat hay, salt and bran recovered if the ration were changed to oats, alfalfa hay, green forage, hay and bone meal. The latter is much richer in minerals, especially in calcium, than the former.

Robertson [15] found that natural recovery frequently occurred when animals in the initial stages of the disease were removed to another district. Lane,[16] who considered the condition similar to osteomalacia, suggested deficiency of lime and phosphorus in the pastures and hay as an important causal factor. He states that it was rare in army horses during the war, owing to the fact that the most of the hay on which they were fed was imported. Ingle [17] carried out an investigation involving the analyses of pastures and hays and concluded from his results that the disease was due to the low ratio of calcium to phosphorus in the pastures and hay. As a matter of fact, however, his analyses showed great poverty of both these elements in the herbage. Thus, in six samples of hay from different districts in which the disease occurred the average percentage of calcium as CaO was 0·135 and of phosphorus as P_2O_5 was 0·278. Malnutrition with bone lesions would be certain to develop in animals fed continuously on forage, or grazing on pasture, so deficient in calcium and phosphorus, apart altogether from the effect of lack of balance.

The most recent work seems to point to deficiency of calcium as an important etiological factor. Dekker,[18] who studied the condition in Padalarang in the Dutch East Indies, came to the conclusion that the fodder plants were deficient in lime owing to lime deficiency in the soil. He advocated the adding of phosphate of lime to the ration of horses, and the liming of the land as a means of increasing the lime content of the pastures. Müller [8] states that since these measures have been taken osteoporosis has practically

disappeared from that district. In Ceylon the results of recent experimental tests have shown that the administration of calcium salts effectively prevents the onset of the disease (Sturgess [6]). This work, if confirmed, definitely pins down deficiency of calcium as at least one cause of the disease.

An interesting note bearing on the subject has been made by Scott [19] in Victoria, Australia. When the herbage is of inferior quality, horses eat the bark of " grey-box " trees, and analyses of the ash of the bark of this tree showed that it was exceedingly rich in lime, containing 53·7 per cent. compared with 2·70 per cent. in native grasses. Scott regards this eating of the bark as a form of pica, the animal being drawn to feed on the bark in order to supplement the scarcity of lime in the pastures.

Although deficiency of minerals, especially of lime, has been put forward as a cause of this condition, this view is not accepted by all writers. Thus, Sourrel,[20] who studied the condition in Tongkin, could find little difference between the amounts of mineral salts in the native forage and in that imported from France. He therefore doubted the deficiency of lime theory. Thiroux,[7] writing on the condition in Madagascar, regarded it as an infection, on account of the fact that imported horses suffered, whereas native horses were immune. Robertson [15] believed it to be a contagious disease. Theiler,[21] however, was unable to convey the disease by blood transfusions. He, however, considered the possibility of an insect-borne micro-organism being the causal agent. Mohler [1] considers that the theory of deficiency of lime and phosphates as a cause of the disease can be disproved on account of the fact that it occurs on limestone soils in New York State and in animals which are well fed. He states, however, that beneficial results have followed the addition of lime to drinking waters, and recommends change of grazing as a cure.

It is probable that all cases of osteoporosis may not be due to the same cause. Any condition, or set of conditions, which prevented the assimilation by the animal of the necessary amounts of calcium and phosphorus, would tend to result in the decalcification of the bones, and the general malnutrition found in osteoporosis. It is probable that in some cases, probably in most, actual deficiency of calcium or phosphorus in the pasture or forage is the cause, and that in other cases, though there is no actual deficiency, the results of a bacterial infection or some dietary factor, such as a wrong balance of the constituents, might interfere with the normal processes of assimilation. The disease is almost always found in areas where the mineral content of pastures is known to be low or abnormal. The statement by Mohler that it occurs in limestone districts in New York State is the only reference we have been able to find of it occurring on a rich soil. In this case, however, deficiency of phosphorus may have been the cause. This frequent occurrence on deficient areas and the fact that calcium salts or bone meal have been found to be beneficial and are recommended, even by the writers who considered the disease to be bacterial in origin, support the view that deficiency of either calcium or phosphorus in the pastures or forage is an important etiological factor in the disease.

Kumri.—Davis,[22] who has shown that the vegetation of Bihar and Bengal is very deficient in phosphorus, has suggested that "kumri," a disease in horses associated with paralysis, which occurs in these districts, may be due to phosphorus deficiency. There is, however, not sufficient evidence available to enable an opinion to be formed as to what rôle deficiencies in the pasture play in this disease.

Association of Composition of Pastures with Quality in Horses.—Just as there are definite areas in which osteo-

porosis tends to occur, there are on the other hand districts which are recognised as being specially suitable for the breeding and rearing of horses with good bone and stamina. In these districts the pastures are rich in bone-forming elements. In Britain the districts which are traditionally famous for horse breeding are in the lime-rich areas of Ireland or the chalk downs in the South of England.

There is some evidence to show that when horses are transferred to poor pastures the breed deteriorates. Dr. Cameron of Victoria has informed the writer that the offspring of English race horses imported into Australia are inferior to their parents which were reared in England. He attributes this to the phosphorus deficiency in the pastures. An excellent example of deterioration occurs in the Falkland Islands, the pasture of which is extremely deficient in calcium. Munro,[23] in his report on these islands, states that " it is well recognised that after breeding from local mares and stallions for a few successive generations the progeny become reduced to the size of ponies, and for this reason horses must be regularly imported from South America for breeding purposes." The following comparison between the mineral content of the pastures of the Falkland Islands, where this rapid deterioration occurs, and that on Lord Astor's paddocks in Buckinghamshire, where some of the best racehorses in the world are reared, is of interest (Godden [24]):

	Silica-free ash.	CaO %	P_2O_5 %	Na_2O %	K_2O %	Cl %	N %	Fibre %
Falkland Islands	3·91	0·225	0·488	0·290	1·980	0·580	1·650	29·39
Lord Astor's Paddock	8·68	2·473	0·997	0·698	2·398	0·498	3·562	20·25

Bone meal or salt mixtures have been administered to breeding mares and foals for the purpose of increasing their size and vigour, but the writer is not aware of any experiments which have been carried out with controls. Experi-

ments of this nature would be of interest, especially in districts where the pastures are known to be deficient in minerals, and where deterioration of the breed occurs and is suspected to be due to this cause.

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CHAPTER XI

EFFECT OF MINERAL INTAKE ON RATE OF PRODUCTION OF GRAZING ANIMALS

In the preceding chapters it has been shown that pathological conditions may arise through deficiency of minerals in the pastures, and that the development of this condition can be prevented either by the direct administration to the animal of the deficient minerals or by the enrichment of the pasture through the application of mineral fertilisers to the soil.

As will be seen in this chapter, it was found that accompanying the prevention of disease by these measures, there was increased rate of growth in animals and increased production in adult females. This increased production is of more economic importance than the mere negative aspect of preventing disease, because while the grazing areas in which deficiencies are so extreme that diseases develop, are limited to certain definite districts, most of the pastures of the world are capable of improvement from the point of view of their mineral content.

The present chapter deals with this aspect of the effect of the mineral content of pastures on the nutrition of grazing animals. It gives an account of the effects on growth and production of (*a*) the administration of mineral salts, and (*b*) enrichment of the pastures by mineral fertilisers.

Direct Administration of Mineral Salts.

Sodium Chloride.—The first minerals which were fed to grazing animals were those contained in what has been referred to in the literature as "salts." References to the value of salt for animals are found in the ancient classical writings. It was believed to have a special influence on fecundity. Plutarch [1] refers to its influence in increasing fecundity in mice, and fourteen centuries later Bernard Palissy [2] refers to the belief that salt aids the generation of all animals. Both Pliny [3] and Virgil [4] extol the value of salt for milk production.

From the middle of the eighteenth to the middle of the nineteenth century there are many references in agricultural literature to the value of salt for animals. Brownrigg (London) [5] wrote a treatise on the "Art of Salt." He says, "Black cattle licking salt thrive to admiration," and he refers to the high nutritive value of the pasture of salt marshes, which indeed had been noted by several early writers. Treatises on the use of salt were written also by Hollinshead (Blackburn, 1800),[6] Parkes (1819),[7] Dacre (Manchester, 1825).[8] Parkes refers to the beneficial practice of feeding salt either as a lick or mixing it with hay as a winter feed. He gives an account of the benefits that accrue from the use of salt for both cattle and sheep on the continent, and gives the following quotation from the *History of the Royal Society of Medicine*, Paris (1778): "In the district of Chamsaur and the adjacent countries we are accustomed to give every ox and cow four ounces of salt every eight days, and about an ounce to every sheep and goat at the same intervals. When this practice is neglected the animals eat less; they lose their spirits; their hair rises; they go licking in their stalls the bottom of their walls where the saltpetre is formed; they grow lean,

become barren, and disease ensues." Ambrose Blacklock in 1838 [9] refers as follows to the value of salt for cattle in South America : " When the wild cattle of South America greatly increased, they could not exist unless they had access to streams which had acquired brackish particles from the soil. If the salt, in places devoid of it, was not furnished to them by man, they became stunted, unfruitful, and soon disappeared." Dacre [8] writing in the same year recommends farmers to carry out tests with salts and indicates the beneficial nature of the results which they are likely to get. So far as we can discover, however, the first systematic tests were done, not in England, but in France. Boussingault,[10] that indefatigable investigator of agricultural problems, carried out a series of systematic experiments with controls and recorded the resulting data. He found that the giving of 34 grams of salt per head per day to young bullocks grazing on pasture or fed on hay resulted in an increased rate of growth. The increase in weight, however, was not very marked, that in the salt group for twelve months being 118·8 kgs. per 100 kgs. initial live weight, compared with 111·1 kgs. per 100 kgs. initial live weight in the controls. A similar result was obtained with lambs. Tests were also carried out by Mathieu de Dombasle, Turck, Daurier, Husson, Lequin and Dailly. The results are recorded by Barral [11] in 1850, who gives a review of the literature of the subject. They show that, in both cattle and sheep, the addition of salt was accompanied by an increased rate of growth. An interesting statement is made by Jullien,[12] writing on the salt tax in France. He says that, " the Jura mountains are a boundary—on both sides the pastures are rich, but on the Swiss side the cows are healthy looking animals producing a good quality of milk and healthy calves, while on the French side the cows look miserable, develop rickets, and are generally unhealthy.

The same happens on the Spanish and French sides of the Pyrenees. This difference is due to the lack of salt from which the cows are suffering owing to the tax on salt."

More recently observations on the value of salt for milk cows have been made by Babcock and Carlyle.[13] They found that the requirements for salt were high, amounting to one ounce per day for cows in milk, heavy producers requiring still more. They conclude that 0·75 ounces daily per thousand pounds live-weight with 0·3 ounces in addition for every ten pounds of milk is generally sufficient. Deficiency of salt led to decreased milk yield and loss of condition. This could be prevented by either sodium chloride or potassium chloride, indicating that chlorine and not sodium was the limiting factor. These tests were carried out with animals indoors. It is possible, however, that they have a bearing upon grazing cows, as some pastures are very poor in chlorine (pp. 13 and 21).

The value of common salt for animals was thus well known to older generations of stockmen. It is possible that its value was over-emphasised. This may account for the fact that in British farming during the last half century the use of salt has tended to be neglected by some stockmen.

There are some modern references to the value of salt for stock in the literature of the Dominions and Colonies. Reid,[14] for example, emphasises its importance for sheep in New Zealand. In hot climates a specially generous allowance is required on account of the fact that sodium chloride is lost in perspiration. Under these conditions the pica for salt becomes so intense that animals will lick the clothing of the perspiring stockman, and the eagerness of cattle for salt may be so marked that the person distributing it by hand is in danger of getting trampled on. In India horses need relatively large amounts, and the administration is a routine practice in all well-conducted stables.

Calcium and Phosphorus.—Most of the early writers who advocated the giving of salt to animals grazing on pasture or fed on hay regarded salt rather vaguely as a tonic or stimulant of the appetite, in short, somewhat of the nature of a medicine, rather than what it is—a compound of two essential food constituents, sodium and chlorine, which are needed in definite amounts just like the other food constituents. The conception of the balanced ration in which not only sodium and chlorine, but also calcium, phosphorus and the other mineral elements, are present in the right amounts in relation to the organic nutrients is comparatively recent. Indeed, the idea that there could be a deficiency of phosphorus or calcium arose only from the study of the pathological diseases which develop as a result of these deficiencies. The direct feeding to grazing animals of minerals apart from salt is, therefore, a recent development. It is indeed only at the experimental stage.

The most striking results on record are those obtained at the Armoedsvlakte Station in South Africa by Theiler, Green and du Toit.[15] Several years ago these workers began a systematic investigation which is still being continued. The results obtained to date are so remarkable and of such great potential economic importance that a detailed reference to some of the data is warranted.

The deficiency of phosphorus in the pasture on which the experiment was carried out was so marked that it was the direct or indirect cause of disease (p. 80). Bone meal supplying phosphorus and calcium with traces of other minerals was fed to young growing cattle at the rate of three ounces per head per day. Similar cattle grazing on the same pasture, but receiving no bone meal, served as controls. The result is shown in the following table :

	Bone Meal.		*Nil.*	
	No. 518	No. 502	No. 475	No. 528
Increase in wt. in lbs. -	445	422	146	154

Post-mortem examination brought out the important fact that the carcases of the animals receiving the additional phosphorus in the form of bone meal had a higher proportion of their live weight in the form of butcher-dressed carcase than the others. They carried more meat and fat in proportion to skeleton and entrails, and the muscle fibres were more liberally interlarded with the fat. It is obvious from these results that phosphorus was the limiting factor for the utilisation of those organic food constituents in the pasture which are transformed to meat and fat.

Another important fact brought out by these tests is that the amount of phosphorus required to prevent diseases which developed through lack of this mineral is not the optimum amount. Some animals were fed bone meal in just sufficient amount to prevent the onset of pica (osteophagia), while comparable animals were given five times as much. The following table shows the results as estimated by increase in weight from January 1922 to May 1923 :

	I. Control. No Phosphorus.	II. Sufficient Phosphorus to prevent Pica.	III. Additional Phosphorus.
Amount of bone meal fed (lbs.)	Nil	15	75
Gain in wt. (lbs.) - - -	166	295	352

The amount fed to Group III. was intentionally in excess of the requirements. It is known that excess of minerals may have an adverse effect on growing animals. It is possible, therefore, that an even better result would have been obtained in Group III. with an optimum amount of phosphorus.

Tests with milk cows in the same phosphorus-deficient area show that the feeding of bone meal was accompanied by a 40 per cent. increase in the milk yield compared with controls receiving no additional phosphorus.

The calves of the bone-meal-fed cows were from 10 to 20 per cent. heavier than those of the controls. In a later paper by Malan, Green and du Toit [16] dealing with a continuation of these experiments, it is stated that " in general appearance and in weight the calves of the cows receiving bone meal showed a marked superiority over calves of control mothers and were much more uniform.... In general the character of the unweaned calves bore definite relation to the extent to which the mother suffered from aphosphorosis." In feeding tests with sheep in Scotland, referred to later in this chapter, it has been noted that the improvement in quality of the sheep receiving supplementary feeding making good deficiences in the pasture, is more marked in the second generation. These preliminary observations in South Africa and Scotland suggest that the deterioration in size and quality of improved breeds which is commonly noted when they are put on poor pasture, is due to a deficiency in the pasture, and could be prevented by appropriate supplementary feeding.

In a recent private communication du Toit has stated that one of the most remarkable results being obtained, as these tests are continued, is the decreased mortality in the bone-meal-fed groups as compared with the controls. This has also been noted in the Scottish tests. In the South African work it has been found that in the cattle on phosphorus-deficient pasture, the inorganic phosphorus in the blood is low compared with that of normal healthy animals. A similar result has been noted by Eckles, Becker and Palmer.[17] It is possible that deficiencies may not only be the cause of definite diseases of malnutrition, but may also, by affecting the tissues or the circulating fluid of the body, be the direct causes of other diseases through the lowering of the natural resistance of the animal.

During the past two years tests with sheep, on somewhat similar lines to those carried out in South Africa with cattle, have been running in Kenya Colony (Orr [18]). A mixture of inorganic salts supplying chiefly calcium, phosphorus, sodium and chlorine, and traces of other minerals, has been fed to sheep and lambs grazing on pasture known to be deficient in these minerals. The following table shows the effect of the minerals on the rate of growth of lambs. There were 45 lambs in each group. The group forming the control received no mineral supplement, while the other group was fed a mineral mixture at the rate of half an ounce per head per day.

	Control.	Mineral Mixture.
Molo (7 months), av. gain in wt. in lbs. -	14·3	18·2
Naivasha (9 months), av. gain in wt. in lbs.	39·7	44·2

The average weight of the fleeces of the mineral-fed lot were in the one case (Molo) about 4 per cent. and in the other 18 per cent. heavier than in the controls.

Somewhat similar tests have been carried out with sheep in Scotland grazing on areas in which the chief deficiency was calcium. These tests, however, are not strictly comparable in so far as, for convenience in feeding, the minerals were made up into the form of little cubes with protein-rich substances and 5 per cent. cod liver oil. The cubes consisted of minerals to the extent of 50 per cent., and half an ounce per ewe per day was fed for the seven months in the year when the mineral content of the pasture was known to be at its lowest. The following figures show the weight of lambs at birth at the various hill farms; there were from 50 to 100 lambs in each group.

Weight of Lambs at Birth.

	Fed.	Control Unfed.
Blairmore, Arran -	7·4 lbs.	7·1 lbs.
Benlester, Arran - -	8·7	7·7
Essiehill, Rowett Institute	9·5	8·7
Edgerston, Singles -	9·0	8·5
„ Twins -	7·3	7·2

The influence on the weight of the fleece is shown by the following table :

WEIGHT OF FLEECES.

	Fed.	Control Unfed.
Blairmore - - -	4·3 lbs.	4·2 lbs.
Benlester - - -	6·0	5·5
Edgerston Ewes - -	4·6	4·2
,, Hoggs -	4·8	4·3
Watcarrick - - -	3·7	3·3
Terrona - - -	3·8	3·5

The results of these Scottish tests, therefore, are closely similar to those obtained from Kenya Colony.

In Australia salt licks are extensively used. In most cases the main ingredients are sodium chloride and phosphorus-rich substances like bone meal. Beneficial results are reported from the use of these, but unfortunately there are little definite data. Brunnich has been carrying out tests with a phosphorus-rich salt lick whose composition is based on his analysis of the pastures in the areas in which the salt licks are being used. In a private communication, he states that these have given excellent results, especially during drought, *i.e.* in the period when whatever herbage was available would be poorest in phosphorus (p. 42). The sheep consumed about $1\frac{3}{4}$ ozs. per head per week. In one large station the stock carried during the drought period was doubled, and the animals were in better condition, as evidenced by decreased mortality and increased percentage of lambing.

There are on record a number of statements with regard to tests similar to those referred to above. Marcq [19] records that, in the parts of the Belgian Congo, there is a deficiency of phosphorus, which, however, is not sufficiently marked to produce gross signs of disease. The feeding of bone meal is followed by an increased rate of growth in young cattle, and increased milk production in cows,

and the calves at birth are heavier and more vigorous. Schmidt [20] records similar results in Texas, where there is evidence of a deficiency of minerals in pastures. The feeding of bone meal and salt increased the rate of growth in beef cattle, the milk production in cows, and the weight and vigour of calves at birth. Eckles, Becker and Palmer,[21] have noted that increased fertility in cows with increased weight and vigour in the calf at birth has been followed by the use of bone meal on farms where the pasture or hay fed was deficient in calcium or phosphorus.

The beneficial effects on fertility in cows, on the rate of growth of calves, and the milk yield, indicate that work along these lines, viz. : the feeding of mineral supplements to balance up deficiencies in the pasture is likely to yield results of practical value. It is clear, however, that administration of minerals which are not deficient in the pasture cannot be followed by any beneficial results. In good pastures, as has been shown by Woodman and his co-workers,[22] there is not only no deficiency of minerals, but both minerals and protein are in excess, in relation to the caloric or starch value. On these pastures obviously no benefit would follow the feeding of minerals.

Before administering mineral salts to grazing animals it is necessary to determine whether or not the pasture on which they are grazing is deficient, and, if so, the nature of the deficiency. The only method of determining this is by chemical analyses of the pasture.

Increasing the Mineral Content of the Pasture.

As a rule the application of fertilisers has had for its object the improvement of the plant, and its results have been judged from its effects on plant nutrition. It has been shown, however (Chapter III), that the mineral content of pastures can be increased by the application of mineral

fertilisers to the soil. It might be expected, therefore, from the results of direct feeding of minerals to animals on poor pastures, that the application of mineral fertilisers on such pastures would be followed by a beneficial effect on the animals. As a matter of fact, experiments, in which the results of the treatment of the soil was looked for in the animals rather than in the plant have been carried out.

As in the case of feeding mineral salts direct to animals, the earliest reference we have been able to find with regard to the application of mineral fertilisers to pastures, is in connection with the salting of pastures. Several early writers advocate the use of salt as a manure. Hollinshead [6] gives an account of the treatment of a field in which horses and cattle would not thrive. He says : " 16 bushels of foul salt were sown in April 1778, and ever since it has been perfectly green and cattle of all kinds thrive on it remarkably well."

Wright (1858),[23] one of the earliest investigators with mineral fertilisers other than salt, had the idea quite clearly that some pastures were of low feeding value because they were too poor in bone-forming elements, and he applied ground bones with the direct object of increasing the amount of bone-forming material in the herbage. He says, " Where impoverished, ill-looking animals are found, there is probably a want of this invaluable ingredient in the herbage." He carried out tests on poor pasture and found that after a dressing with 7 cwts. ground bones per acre, the land carried " one half more stock combined with great improvement in the state of the stock themselves at the end of the summer."

The recent work of Somerville [24] and his co-workers is on similar lines, though they did not pay attention directly to the mineral content of the soil and of the pasture. They showed that the application of slag (*i.e.* a combination of

phosphorus, calcium and other inorganic elements) resulted in the growth of a pasture which had a much higher feeding value ; the live-weight increase on plots receiving basic slag being sometimes as much as six times as great as that on adjoining untreated plots. These tests which began at Cockle Park in 1897 have been repeated at other English centres with equally marked results. In similar tests begun in Scotland in 1901 and carried on for ten years by Wilson [25] and Hendrick, [26, 27] the results were less striking, the difference being evidently due to the fact that in the Scottish soils on which the tests were made, phosphorus was not the limiting factor to the same extent as in the case of the soils on which the English tests were done.

The beneficial effect of the application of these mineral fertilisers was not due merely to an increase in the quantity of the herbage. Hendrick makes this clear. In discussing the seasonal differences in nutritive value of pastures in connection with these tests, he states that the differences were due not to increase in quantity but to the factors affecting the nutritive properties. Somerville also recognised that the improvement was in the quality of the pasture rather than in the quantity. He noted that animals on the improved pasture did better than animals on the unimproved, although the latter were receiving concentrates in addition to the poor pasture. In later work by Richardson [28] in Australia, the pastures were analysed, and the data showed that the increase in the feeding value was connected with an increase of calcium, phosphorus and nitrogen.

It is unnecessary to refer in detail to the general improvement which occurs in most pastures through an application of the proper mineral fertilisers. This method of treatment of pastures has in the past few years become established as a routine practice in good stock farming. It is a matter of common observation that the yield of the

pastures and their carrying capacity are increased. In many cases the carrying capacity is doubled. This improvement has been effected not only in natural pastures but also on cultivated lands (James Cruickshank [29]). The most extensive improvements, however, have been effected in the grazing lands of New Zealand, Victoria and the Southern parts of Australia. In Australia the carrying capacity in some districts has been more than doubled and the rate of growth of the sheep has been increased, so that these improved pastures carry a larger framed sheep. Unfortunately the improvement of Australian pastures tends to be accompanied by a deterioration in the quality of the wool, the larger sheep on the improved pastures having a stronger wool than the smaller sheep on the poorer pastures.

A beneficial effect similar to that noted in the case of sheep in Australia has been noted in the case of dairy cattle in New Zealand. In that Dominion, phosphatic dressings are extensively and regularly applied throughout the dairying areas, and this practice has materially aided in the maintenance of health and vigour in dairying animals, in improving the average butter fat production per cow, and increasing the carrying capacity of the pastures (Reakes [30]).

There is little doubt that within the next few years mineral fertilisers will be used in increasing quantities with the object of increasing the carrying capacity of the pastures, and increasing the rate of production of the animals grazing on them.

It is interesting, in view of what is known in regard to the pica of animals suffering from deficiency of minerals, to note that grazing animals show a decided preference for the pasture which has been top-dressed. The results of the Scottish work (Chapter II) showed that with poor hill

pasture in Scotland, where the herbage is in abundance but is of poor feeding value, grazing animals collect the material which is richest in minerals. Mullett,[31] in discussing this "strong preference" shown by animals for top-dressed pasture expresses the view that it is due to the higher food content, especially phosphate of lime.

Of the two methods of increasing the mineral intake of grazing animals, the indirect method, viz.: the application of mineral fertilisers to the soil, is the better, because in addition to enriching the pasture in mineral nutrients, it increases its feeding value in other ways. It raises the percentage of protein and increases the actual quantity of pasture. The direct method, viz.: the administration of substances rich in minerals to make good the deficiencies of the pasture can, however, be carried out at a much lower cost per head of stock. There are many areas where the application of mineral fertilisers to the soil is an economic impossibility. In these areas the feeding of mineral supplements may give an immediate return for the cost. Further, as the amount fed must be about double what the animal can absorb and utilise, there is a residue which passes to the soil in the excreta. This residue is small, but the cumulative effect from a number of years would tend to the enrichment of the soil. In areas where depletion is going on it would at least change the downward trend of depletion to an upward trend of gradual enrichment.

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CHAPTER XII

SUMMARY AND CONCLUSIONS

It has been shown that good cultivated pasture on which grazing animals thrive is rich in mineral nutrients, the amounts and proportions of these reckoned on a basis of equal caloric or "starch value" being very similar to those found in cows' milk. In this respect, therefore, good pasture is a well-balanced food for young growing ruminants or for milk cows.

Natural pastures are as a rule poorer in minerals. In inferior kinds the poverty may be very marked. Thus, in some the percentage of calcium is less than one-fifth of that found in good grazings. Poverty in phosphorus, especially after drought, may be even more marked.

Evidence has been adduced to show that the mineral content of a pasture is an important factor in determining its feeding value. This is partly because minerals are essential food constituents, and hence deficiency of one or more limits the utilisation of the other food constituents, and partly because deficiency of minerals is usually associated with deficiency of protein and the absence of properties such as leafiness and succulence on which the nutritive value of pasture depends.

In cases of extreme poverty, lack of one or other of the minerals may be the cause of disease in the grazing animal. The pathological conditions due to these deficiencies have received various names in different parts of the world, but

the symptoms and lesions fall into definite groups according to the nature of the deficiency. Thus, " styfsiekte " in South Africa, " coastal disease " in Australia, the " creeps " in Texas and " Waihi disease " in New Zealand, which are all due to deficiency of phosphorus, have essentially the same symptoms. In the same way osteoporosis due to lack of calcium, goitre due to lack of iodine, or anaemia due to lack of iron, present similar symptoms in whatever part of the world they occur. A future nomenclature will connect the disease with the cause.

Many of the workers who studied these pathological conditions were evidently under the impression that they were dealing with a localised condition of little more than local interest, but when all the information is brought together, it is apparent that disease due to mineral deficiency occurs in fairly large areas in most countries.

It is only in certain areas, however, that the deficiency of one of the elements is so extreme that the grazing animal develops symptoms and lesions sufficiently acute to warrant the term " disease." In much wider areas there is a general poverty in minerals which, while less extreme than that causing disease, is still sufficient to affect the feeding value of the pasture. In these areas the rate of growth of young animals is slow, the milk yield of cows is poor and the fertility of females is low. Improved breeds imported from richer pastures to these areas tend to deteriorate. These troubles are common in new countries where animal husbandry is being developed on natural pastures.

It has been shown experimentally that the administration, to grazing animals on deficient pastures, of inorganic salts or other substances rich in the elements which are lacking in the pasture, prevents the development of the deficiency diseases referred to above, and also leads to a general improvement in the condition of the animal, with a

rate of growth and milk production nearer to that obtained on good pastures.

This is being done successfully in the case of cattle, and is being attempted in the case of sheep. In most cases there are local difficulties in the application of this method of balancing up the pastures by the direct feeding of whatever is lacking in them. Where it can be done, however, the beneficial result is out of all proportion to the trifling cost of the material fed. As the present methods are improved as the result of field trials, there is likely to be a considerable extension of this practice.

It seems hardly necessary to point out that the administration of inorganic salts or other substances will have a beneficial result only in cases where what is fed makes good a deficiency in the pastures. Good pastures, as we have seen, contain sufficient of all the mineral nutrients, hence the feeding of inorganic salts to animals on good pasture is unnecessary, and unlikely to be followed by appreciable benefit. In the case of poor pastures, the nature of the deficiency should be ascertained before attempting to feed anything in the nature of a mineral mixture. In most cases this can be done only after systematic examination of the pastures, including chemical analysis.

The natural method of increasing the supply of minerals to the grazing animal is by the enrichment of the pastures. Within limits, the composition of the herbage tends to be a reflection of the composition of the soil. The application of lime or phosphates to a soil poor in these, enriches the mineral content of all the species grown on it, and also promotes the spread of plants naturally rich in minerals. It also improves the quality of the pasture in other ways, and in addition usually increases the quantity. It is recognised, of course, that other soil factors, especially the physical condition and the amount of moisture present,

affect the growth of the plant and its chemical composition. In pasture husbandry these factors are usually taken into account.

Whatever the composition of the soil, the stage of growth of the plant affects its mineral content. Young plants in the growing leafy stage are much richer than the old plants. Hence there is a seasonal variation, especially in the percentages of calcium and phosphorus. These increase in the early part of the summer until the plants are at the stage of maximum leaf and most active growth. They then decrease as the plants approach maturity. Associated with this seasonal variation is the influence of drought, which stops growth, and may reduce the percentage of phosphorus to abnormally low levels.

These factors which affect the mineral content of the herbage have a direct bearing on practical pasture problems. The composition of the soil can be improved by the application of fertilisers. It can also be changed in the opposite direction by depletion. This process of depletion and the resulting deterioration which shows itself in decreased rate of growth and production, and in extreme cases by the appearance of disease, is proceeding on all pastures from which milk, carcases or other animal products are taken off without a corresponding replacement being made. Accompanying the visible movement of milk and beef, there is a slow invisible flow of fertility. Every cargo of beef or milk products, every ship-load of bones, leaves the exporting country so much the poorer. In many of the grazing areas of the world this depletion has become a serious economic problem. In Scotland, for example, generation after generation of sheep have been taken off the hills with little compensatory return. Accompanying the resulting deterioration of the pasture, the stocks tend to be reduced in the rough hill grazings.

The extent to which decrease of stocking has taken place in the Highlands and Islands of Scotland during the last fifty years has been brought out in an enquiry instigated by Sir Robert Greig. In the group of Counties—Argyll, Inverness, Ross and Cromarty, Sutherland, Perth—*i.e.* those covering the greatest proportion of mountain and heath grazings of the mainland and the whole of the Hebrides, there has been a decrease of 11·5 per cent. in the cattle and 22·7 per cent. in the sheep compared with the increase of 11·2 per cent. in the cattle and 19·5 per cent. in the sheep for the remainder of Scotland. Figures are available for eight individual counties. The following table shows the increase or decrease in stocking in these counties :

Counties.	Mountain and Heath Grazings.	% Increase or Decrease in grassland (Hay & Grazing) excluding Mountain and Heath.	% Increase or Decrease in total Cattle.	% Increase or Decrease in total Sheep.
Sutherland	29,000	40	−38	−32
Argyll	12,014	19	−13	−38
Stirling	1,328	20	− 1	− 6
Ayrshire	1,095	7	+14	− 4
Forfar	811	15	− 6	+48
Berwick	403	35	+52	+37
Aberdeen	310	18	+ 6	+72
Fife	75	29	+ 9	+66

It will be seen that in the counties with the large areas of mountain and heath, even though apart from mountain and heath there has been an increase in the grassland, there has been a heavy decrease in the stock, whereas on richer lands, where better farming practices, including the application of manures and fertilisers, are in vogue, the carrying capacity is being maintained.

The reduction of the stocks, especially the cattle, has allowed increasing amounts of the herbage to grow up uneaten. In the autumn the fibrous mineral-poor vegetation

dies down and forms a spongy mat which becomes water-logged. This mat slowly increases, separating the spring growth further and further from the true soil. The process of bog or peat formation is going on in many parts of the moors in Scotland at the present time. This process of depletion of the Scottish hills has been going on with increasing rapidity since the time when the produce of the animals, instead of being consumed on the land and therefore returned to the soil, began to be driven off to be consumed in the industrial areas. There are now districts in the Highlands which could not support populations which once lived there, even [illegible] willing to accept the standard of

ERRATUM.

Table, page 142, first column, *read*—Mountain heath grazings, per 1,000 acres, crops and grass.

questions in Scotland. Roughly, about half of the country consists of hills and moors. Great parts of this are, of course, quite useless. Other parts, however, are capable of improvement. It is in these parts that an attempt should be made to arrest the downward process of deterioration which is accompanied by a reduction in the grazing stock and in many cases by an increase in the incidence of disease in the stocks which remain (p. 54).

Scotland has been taken merely as an example to illustrate the evil effects of long-continued depletion. There are other natural grazing areas in the world from which animal products are being removed for consumption in the cities of the same country or for export. Reference has

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This impoverishment of the poorer lands which has been going on for the last 200 years must be taken account of in considering the political question of depopulation. Before the population can be increased it will be necessary to get back into the land the lime and phosphorus which have been taken off it. This is one of the most important political questions in Scotland. Roughly, about half of the country consists of hills and moors. Great parts of this are, of course, quite useless. Other parts, however, are capable of improvement. It is in these parts that an attempt should be made to arrest the downward process of deterioration which is accompanied by a reduction in the grazing stock and in many cases by an increase in the incidence of disease in the stocks which remain (p. 54).

Scotland has been taken merely as an example to illustrate the evil effects of long-continued depletion. There are other natural grazing areas in the world from which animal products are being removed for consumption in the cities of the same country or for export. Reference has

been made to the problem of depletion in some of these areas. Unless measures be taken to maintain, and in some cases to restore the fertility of uncultivated grazings, decreasing production and increasing incidence of disease are likely to prove serious economic problems.

In most parts of the world, as for example in Australia, depletion is associated not with excess of moisture, which leads to peat formation, but with drought, which, however, also accentuates the poverty of the pastures, especially in phosphorus. The extent to which the effects of drought can be minimised by enrichment of the soil has not yet been determined. The problem, which is of great economic importance for many parts of the world, is at present being systematically investigated, and very promising results are already being obtained (p. 43).

The consideration of pastures from the point of view adopted here, *i.e.* its chemical composition and the value of that composition to the needs of the grazing animal, throws new light on an old problem. It gives us a new method of estimating the nutritive value of pastures. It enables us to correlate certain definite nutritional disorders with definite deficiencies, and to correlate the excellence of pasture with the proper balance of nutrients whose amounts can be accurately determined by chemical analysis.

The results of investigations from this special point of view are found to be supplementary to those obtained by the plant breeders and soil chemists, and enable a wider interpretation to be given to their achievements. During the last two or three years, there has been greatly increased interest in pasture, whose true value is now being appreciated, and extensive investigations are being carried out in both the United Kingdom and the Dominions by workers who are keeping in touch with each other and freely exchanging information.

The scientific information we already possess warrants the belief that the carrying capacity of pastures can be much increased and the health and quality of animals grazing in poor pastures can be much improved. The measures taken to attain these ends will result in increased fertility of the grazing lands. It is probable that the total production of the grazing lands of the world can be doubled. This would, of course, mean enormous increase in the primary necessities, *i.e.* in the world's real wealth. Where, however, we are dealing with natural processes where the cycle is completed only once in a year, and the life cycle of the animal is several years, the experiments designed to yield the information which can be applied in practice require several years before the economic results are demonstrable. It is in these experiments testing and applying our acquired knowledge that the main research effort throughout the Empire is now being concentrated. It is possible that if a review of existing information on this subject be written five or six years hence, some of the hypothetical conclusions discussed here may be stated as facts which have been demonstrated, and their economic value proved.

In conclusion, it may be repeated here that this review deals only with the mineral content of pasture, and this limited aspect is viewed from the point of view of the veterinarian who is interested not so much in pasture *per se* as in the value of the pasture for the grazing animal. The consideration of even this limited aspect, however, raises questions connected with plant growth, which in turn involves problems of plant breeding and soil conditions and finally even economics, for it is the question of cost which decides the practicability of any proposal for the improvement and better exploitation of pastures. The combined effort of workers in all these branches of applied science is

needed to solve the great pasture problems. The results obtained by workers in one branch of the subject throws light upon the problems being studied by workers approaching the same general problem by a different avenue. The information which has been accumulated by veterinarians and others interested in the mineral content of pastures, and which has been reviewed here, may throw new light on some of the long-standing pasture problems, and information from whatever source is welcomed by all those who are interested in the exploitation of pastures, a subject on which so much intensive work is being carried on at the present time.

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Aug 8 '41	Woodward	FEB 5 1963
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Nov 20 '42	Woodward	MAR 18 1974
Nov 27 '42		APR 1 1974
Mar 20 '43	Jericho	
Mar 8 '46		MAR 29 RECD
Nov 20 '46	Hinesburg	
JAN 3 1949	Jericho	
Apr 3 1950	Richmond	
Mar 9 1951		FEB
Mar 27 '51	Jericho	
Apr 4 '51		

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